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NATIONAL PHOTOGRAPHIC
INTERPRETATION CENTER

A RECOMMENDED COLOR VOCABULARY FOR COLOR AERIAL RECONNAISSANCE

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NPIC/R-02/72
JANUARY 1972

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SUMMARY

The Center, in its preparation for the possible use of color imagery, has seen a need for a standardized color vocabulary. Thus, the objective of this study was to recommend a vocabulary that could be used (1) to identify and designate the colors of objects or targets appearing on color imagery, (2) to catalogue color-related target signatures, and (3) to communicate color-related information.

The development of a color vocabulary was accomplished by investigating a series of topics that are related to the Center's mission of exploiting small-scale, high-quality color imagery. The following topics were investigated:

(1) The visual problems related to the interpretation of color imagery:

- The color-discrimination capabilities of the average color-normal observer
- The color-matching capabilities of the average color-normal observer
- The color-memory capabilities of the average color-normal observer
- The color-naming capabilities of the average color-normal observer.

(2) The photographic problems related to the interpretation of color imagery:

- Photographic scale and its relationship to the angular size of the target seen by the image interpreters
- Color rendition of the photographic process and its relationship to the color vocabulary.

(3) The anticipated job-related color vocabulary needs of the staff:

- Image interpreters
- Collateral researchers

- Editors
- Model makers
- Scientists and Engineers
- Artists and Illustrators
- Photographic Technicians
- Printers and Pressmen
- Photogrammetrists
- Managers.

(4) The basic concepts, methods of application, and the advantages and disadvantages of the systems used to designate, specify, or identify different colors:

- Munsell
- CIE
- ISCC-NBS
- Lovibond
- Densitometric Munsell
- DIN
- Ostwald
- NuHue
- Plochere
- Ridgway
- Maerz & Paul
- Textile Color Card Association
- Methuin
- Villalobos.

It was concluded from the results of the four topics studied above that the needs of the Center could be satisfied by a trilevel color vocabulary. The first level of this recommended color vocabulary consists of seventeen names: pink, red, orange, brown, yellow, yellow-green, olive, green, blue-green, blue, violet, purple, white, gray, black, cyan, and magenta, and the modifiers, light and dark. Combinations of these color names (except cyan and magenta which are not to be used for image colors) such as red-brown can be used in those few situations where the single names are not adequate to describe the colors. Samples of these colors (except white, gray, and black) are included in the back of this report. The second level of the color vocabulary consists of the Munsell and ISCC-NBS color systems. The degree of precision needed in the visual communication of color-related information determines which of these two color systems are to be used. The ISCC-NBS color system is used when a non-precise visual color reference is required for communication. This system is implemented in normal working and viewing conditions, since the widely separated color samples do not require the use of critical color matching. When a more precise visual color reference is required, the Munsell system is used. All Munsell color matches or designations are made visually, under specified and well-controlled viewing conditions by highly-trained personnel. The third level of the color vocabulary consists of the CIE color-designation system for very precise and accurate color communication. However, to implement this third level, it is necessary to develop a color correction model to account for the effect of acquisition and processing on color fidelity.

In addition, it is recommended that the Center develop the capability for performing accurate and reliable color measurements by forming a colorimetric group.

1.0 INTRODUCTION

The Center, in its preparation for the possible future use of color imagery, has seen a need for a standardized color vocabulary. The need for such a vocabulary can be fully appreciated when one tries to read and understand a report which contains color names such as Robin's Egg Blue and Sea Foam Mist. The actual colors these names represent are unclear to all, including those individuals who initially suggested their use. Because of the wide distribution of the information generated by the Center and the credibility given to this information, it is important that the Center have ready for future use a standardized color vocabulary whose terms are clearly understood by all those who might use the information published by the Center. Thus, the objective of this study was to recommend a vocabulary that could be used (1) to identify and designate the colors of objects or targets appearing in color imagery, (2) to catalogue color-related target signatures, and (3) to communicate color-related information.

The development of a color vocabulary was accomplished by investigating a series of topics that are related to the Center's mission of exploiting small-scale, high-quality color imagery. The following topics were investigated:

(1) the visual problems related to the interpretation of color imagery

(2) the photographic problems related to the interpretation of color imagery

(3) the job-related color needs of the Center's staff

(4) the methods used to designate, specify, or identify different colors.

A detailed analysis of each of these topics can be found in Sections 2.0, 3.0, 4.0, and 5.0 of this report.

The color vocabulary that is being recommended for use by the Center was based on the conclusions reached by these investigations and is discussed in Section 6.0 at the end of this report.

2.0 THE VISUAL PROBLEMS RELATED TO THE INTERPRETATION OF COLOR IMAGERY

The ability of the average color-normal observer to accomplish various color-related visual tasks was considered to be one of the major factors in determining the type of vocabulary that might be used by the Center. Special emphasis has been placed on the visual aspects of color because nearly all of the tasks require the image interpreters, the photoscientists, or other individuals to examine the imagery visually and then make some judgment, comment, or decision. With the introduction of color, it is anticipated that the Center's personnel will continue to perform all their present tasks as well as some new color-related tasks. For example, the image interpreter might be expected to name the colors of objects that appear in the imagery in addition to the identification and enumeration of these objects. Thus, the type of color vocabulary that might be used depends in part on the ability of an observer to perform certain types of visual tasks such as color-naming and color-matching.

Unfortunately, much of the reported experimental data that have been collected on the color capabilities of the average color-normal observer were collected by using a few color-normal subjects who viewed structure-free colored areas under very controlled viewing conditions. It has been possible in such carefully controlled experiments to determine a one-to-one correspondence between the physical stimuli (e.g., intensity, wavelength, angular size of field) that were presented to the subject and the visual impression (e.g., name of color, apparent size, saturation) these physical stimuli created for the subject. Although much of this information that is contained in the literature on the subject of color perception may not be directly applicable to the Center's problems, it can be used as a guide for determining the general range and nature of the color capabilities or color-related skills of an average color-normal observer.

The color capabilities or color-related skills of the average color-normal individual that are of primary importance to the Center are the following:

1. Discrimination
2. Matching
3. Memory
4. Naming

These four categories are directly applicable to the development of a color vocabulary for the Center. Furthermore, the measure of the ability of the subject to perform one or more of the above tasks (i.e., discrimination, memory) includes the effects of secondary perceptual problems such as after-images, simultaneous color contrast, color constancy, and adaptation due to lighting conditions. A detail analysis of the color-discrimination, color-matching, color-memory, and color-naming capabilities of the average color-normal individual are given in Sections 2.1, 2.2, 2.3, and 2.4 respectively.

2.1 THE COLOR-DISCRIMINATION CAPABILITIES OF THE AVERAGE COLOR-NORMAL OBSERVER

The term color discrimination is used to designate or denote the ability of the average color-normal observer to distinguish between colors that differ in some combination of hue, saturation, and lightness. The color-discrimination ability of a typical color-normal observer is shown in Figure 2.1 and Figure 2.2. Although these data were collected by using a single observer and at a constant lightness level, they are quite representative of the other color-discrimination data that have been collected by using several experimental subjects. The size of these color-discrimination ellipses as plotted on the CIE diagram can be used as a measure of the color-discrimination ability of the average color-normal observer. It has been estimated on the basis of the size of these ellipses that the average color-normal can distinguish differences between approximately 7,000,000 colors.

The color-discrimination ability of the average color-normal observer as indicated by the size of the ellipses shown in Figures 2.1 and 2.2 also depends on the viewing conditions under which the observer made his color matches or discriminations. The sizes of the ellipses in Figures 2.1 and 2.2 do not change significantly as the luminance levels of the test and matching fields are varied from approximately 1 to 15 footlamberts. The size of the ellipses increases, i.e., color-discrimination ability decreases, when the luminance levels drop below approximately 1 footlambert. Although there is no direct experimental verification, it is expected that the size of the ellipses will remain nearly constant as the luminance levels are increased to as high as several hundred footlamberts. The size of these ellipses decrease, i.e., color-discrimination ability increases, when the angular size of the field of view increases. The color-discrimination ability of the average

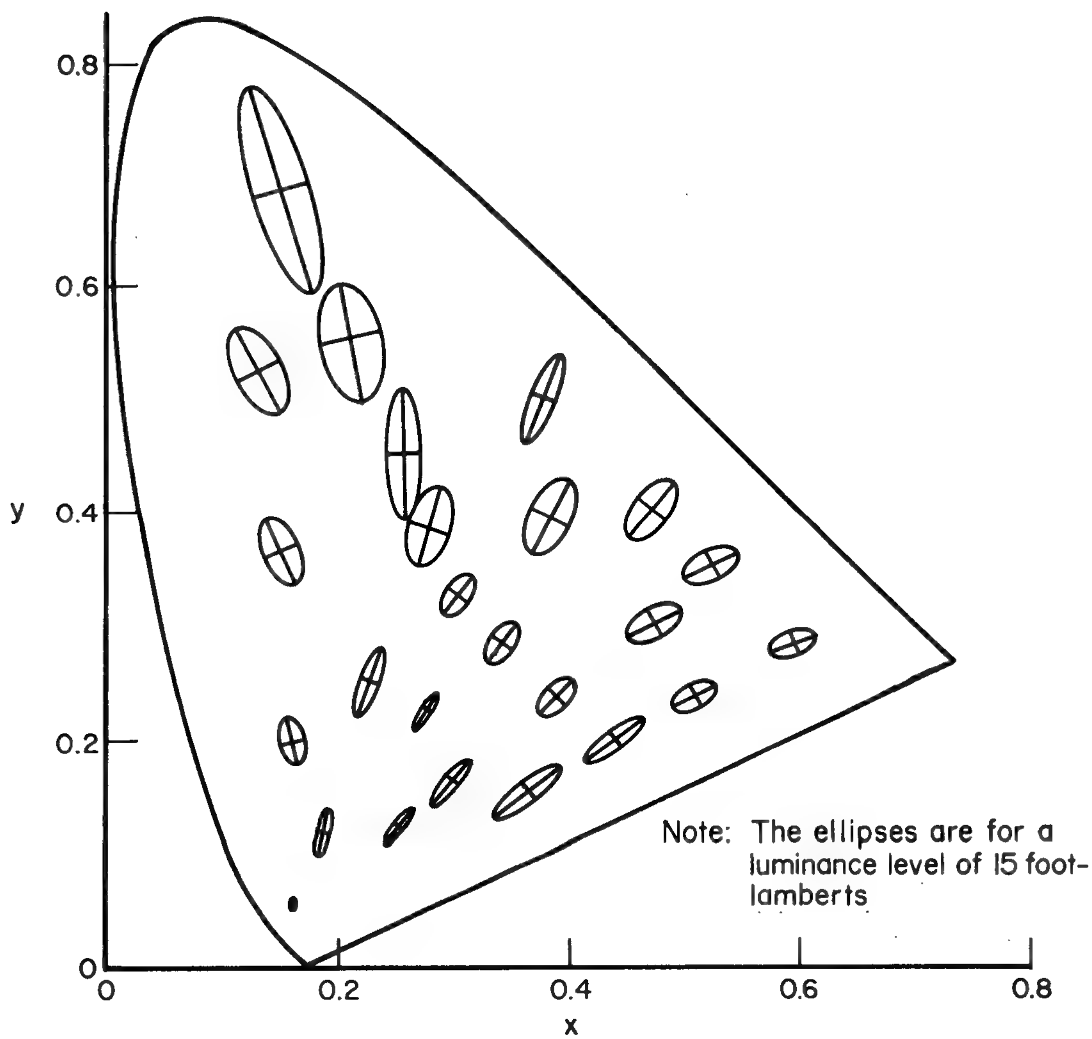

FIGURE 2.1 THE STANDARD DEVIATIONS OF COLOR MATCHES BY OBSERVER PGN, ENLARGED TEN TIMES ON THE 1931 CIE x, y CHROMATICITY DIAGRAM (MacAdam, 1942) (see Section 5.1.2)

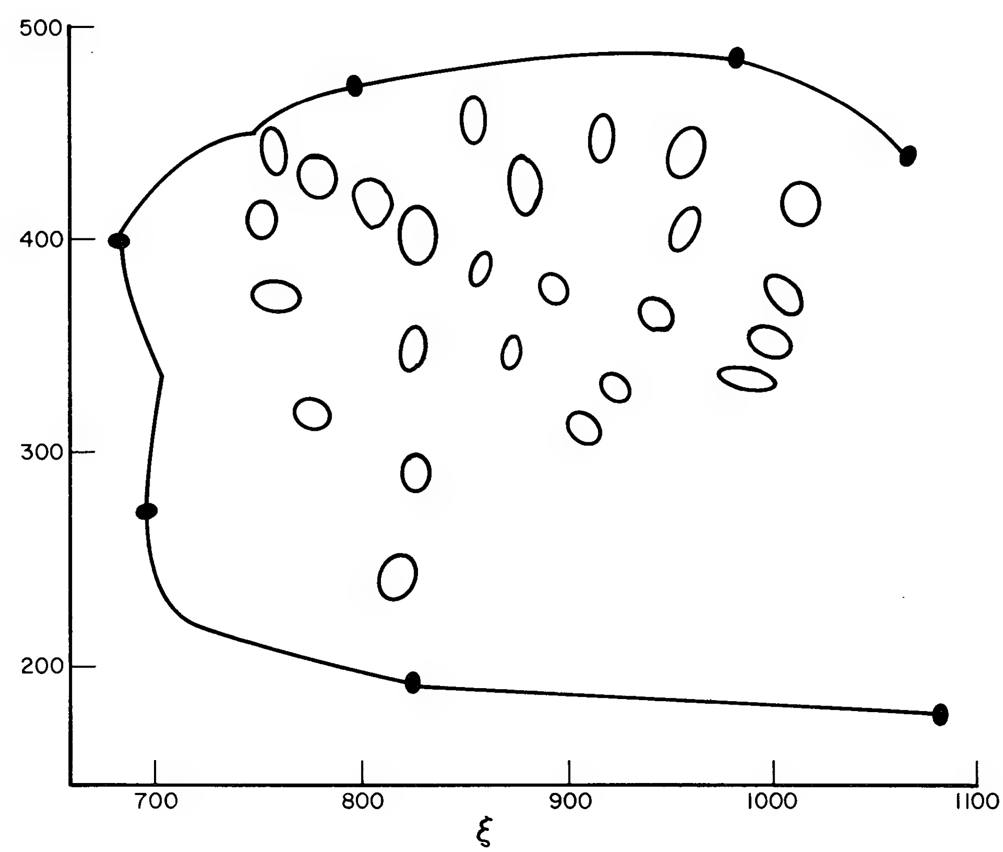

FIGURE 2.2 THE VARIANCES OF COLOR MATCHES - BY OBSERVER PGN, ENLARGED TEN TIMES ON THE ξ, η CHROMATICITY DIAGRAM. (MacAdam, 1971) (see Section 5.1.2)

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observer steadily deteriorates as his field of view is decreased below 1 to 2 degrees. Reliable data have not been collected for fields of view whose angular subtense was less than 3 minutes.

The color-discrimination ellipses for a 3-minute and a 4.40-degree size field of view are shown in Figure 2.3.

The color of the surround has a noticeable effect on the ability of a color-normal observer to discriminate between slightly different colors. This effect is more pronounced when the angular size of the matching and test fields are quite small. For either large or small comparison fields, the color-discrimination ability is greater when the color of the surround is approximately the same as the two colors the subject must discriminate between or match. Therefore, the color discrimination ability of the average observer is more minimal when the color of the surround is the complement of the colors being matched.

The ability of the average color-normal observer to distinguish between spatially separated colors has not been thoroughly studied. However, it is expected that this ability will rapidly decrease as the angular separation between the colors increases.

The general conclusion is that the average individual has a tremendous ability to distinguish between different colors; however, the accuracy and precision with which these discriminations can be made is very dependent upon the viewing conditions. Thus, any color vocabulary must consider not only the discriminatory powers of the human visual system but also its dependence upon the viewing conditions being used by the observers. In addition, at least part of the vocabulary must be able to designate large numbers of colors.

(MacAdam, 1971; MacAdam, 1959; Bedford and Wyszecki, 1958)

2.2 THE COLOR-MATCHING CAPABILITIES OF THE AVERAGE COLOR-NORMAL OBSERVER

The color-matching capability of the average color-normal individual is a measure of his ability to select from a large collection of different colors the one color that has the same or nearly the same hue, saturation, and lightness as a given test sample. The color matches made by a person who is a color normal will be valid only for those viewing conditions that are equivalent to those that existed when the

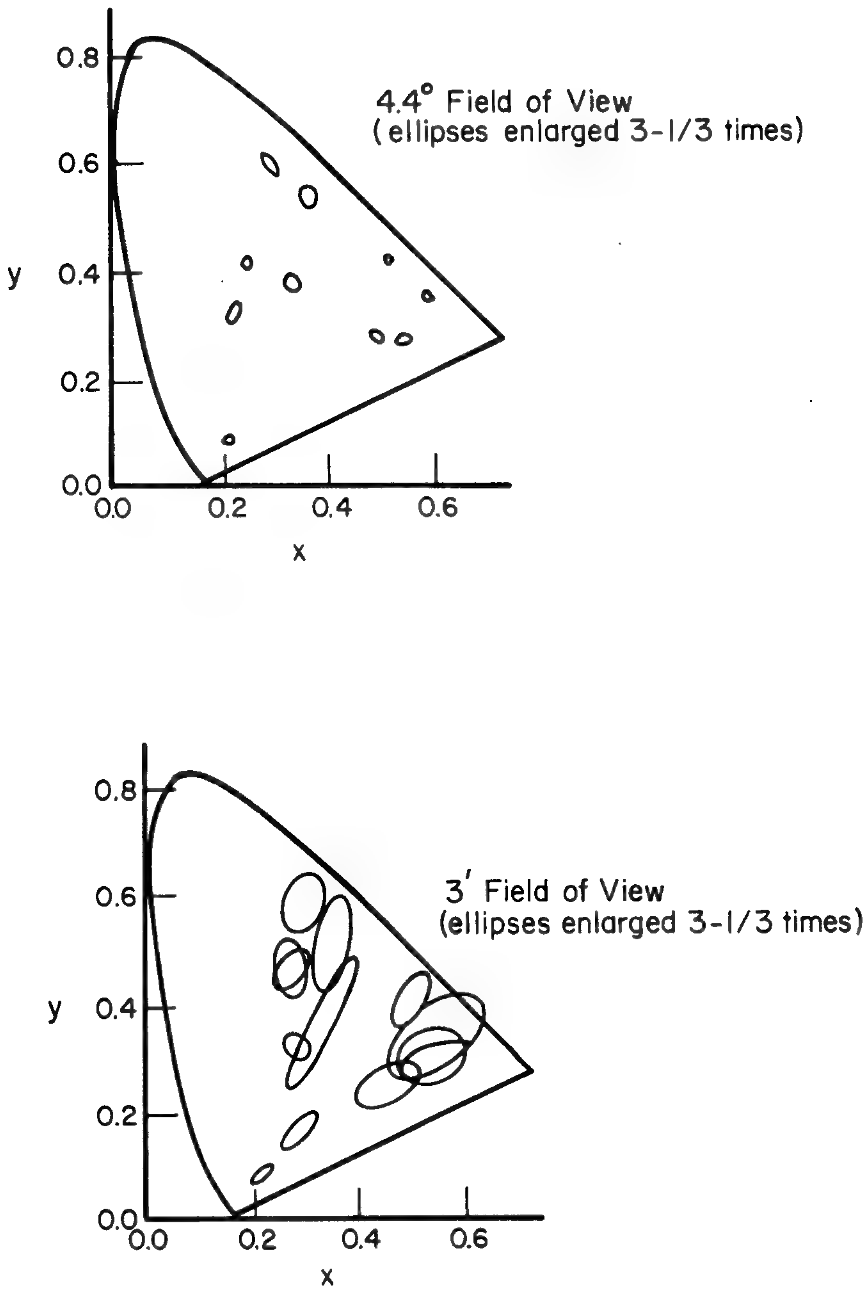

FIGURE 2.3 THE RELATIVE SIZES OF THE COLOR-DISCRIMINATION ELLIPSES FOR A 3' AND A 4.4° FIELD OF VIEW AND A CONSTANT LIGHTNESS. (MacAdam, 1959) (see Section 5.1.2)

match was made. For example, if any of the viewing parameters such as the spectral distribution of the light source, the angular size of the observer's field of view, or the color of the surround are changed, then the original match between the two colors may no longer be valid. Furthermore, the textures of the colors being matched must be the same or nearly so. Although the chromaticity coordinates for the color of a shiny piece of red plastic may be the same as the chromaticity coordinates for the color of rough, red brick, their visual appearance will be quite different.

Even when these viewing conditions are carefully controlled, there will be differences between the matches made by a group of color-normal individuals. Similarly, there will be considerable day-to-day variations in the color matches made by a given individual even if he is trying to match the same set of standard colors. R. M. Evans (Evans, 1948) has estimated that a perfect match between two colors by an average color-normal observer would probably be unsatisfactory for approximately ninety percent of all other observers. This variability among matches made by observers is a result of the extreme sensitivity of their eyes to very small differences in color. These variations can be reduced by controlling and carefully monitoring the viewing conditions and matching techniques that are used.

Much of the data that have been reported on color matching was collected by having a color-normal observer adjust the color in one-half of a bipartite field until it matched the test color appearing in the other half of the field. An analysis of the data collected during the course of such experiments indicated there was more variance in binocular color matches than there was in the monocular color matches. Therefore, monocular color matches may be preferable.

Color-matching experiments also have been conducted to determine the variability between the successive and simultaneous methods. When the simultaneous method is used, the test field or test color is visible while the subject is adjusting the color of the matching field. When the successive method of color matching is used, the subject first views the test color for a given period of time. It is then blanked from his field of view and after a predetermined period of time, the subject adjusts the color of the test field to match what he remembers as being the test color. This latter method is very similar to the way one matches colors in his everyday activities. The successive method takes less time but yields a greater variability in repeated matches of the same colors. Also, those matched tend to be much higher in both saturation and lightness than the matches made by the simultaneous method. It would appear that simultaneous matching should be used.

These color-matching problems place some constraints on the type of vocabulary that might be used by the Center. For example, if each image interpreter were going to read out the colors of every target he sees in the imagery by using some type of a matching scheme, then every light table and viewing instrument at the Center would have to provide their users with the same illumination, angular-size of the field of view, color of the surround, etc.. Furthermore, the texture of colors used by the observer to match the colors of the targets should be the same. This would require a set of standard vocabulary colors of approximately the same granular structure as the color imagery. The use of monocular viewing for color matching should present no real problems in the modification of existing viewing equipment. The use of simultaneous rather than successive matching might produce some problems in the modification of present viewing systems in that some type of split-field viewer would be required. In general, the extreme sensitivity of the eye to very small differences in color indicates that a large commitment in terms of both manpower and money must be made if the vocabulary to be used requires that each image interpreter read out the target's color by some kind of color-matching scheme. (Newhall, Burnham, and Clark, 1957; Hoffman, 1962; Wyszecki and Stiles, 1967; Evans, 1948; Hunt, 1965)

2.3 THE COLOR-MEMORY CAPABILITIES OF THE AVERAGE COLOR-NORMAL OBSERVER

Color memory is the term used to describe the ability of an average color-normal observer to recall and correctly identify the colors of familiar objects. It is indicated by an analysis of the data collected during several experiments that the memories of most individuals are quite unreliable and highly variable. In most cases, the characteristic chromatic attribute of the color of the object was usually exaggerated when recalled from memory. The colors of familiar objects were remembered as being lighter and more saturated. For example, the typical observer remembers the sky as being bluer, the grass as being greener, and the bricks as being redder than the colors indicated by the chromaticity values for these same objects. Similarly, in these experiments, bright objects were remembered as being brighter than they actually were, and dark objects as being darker. Figure 2.4 shows the magnitude and direction of the differences between the chromaticity coordinates for the object and those colors selected by memory. Remembered colors will usually be consistent with what the individual observer has found to be pleasing for a given object, as well as what the object might normally be expected to look like. There are some indications that the color memory of the observer can be improved by training and a considerable amount of practice. If color memory is to be used, then a color vocabulary must be simple and limited to a few colors to compensate for the unreliability.

(Bartleson, 1960; Hanes and Rhoades, 1959; Newhall, Burnham and Clark, 1957)

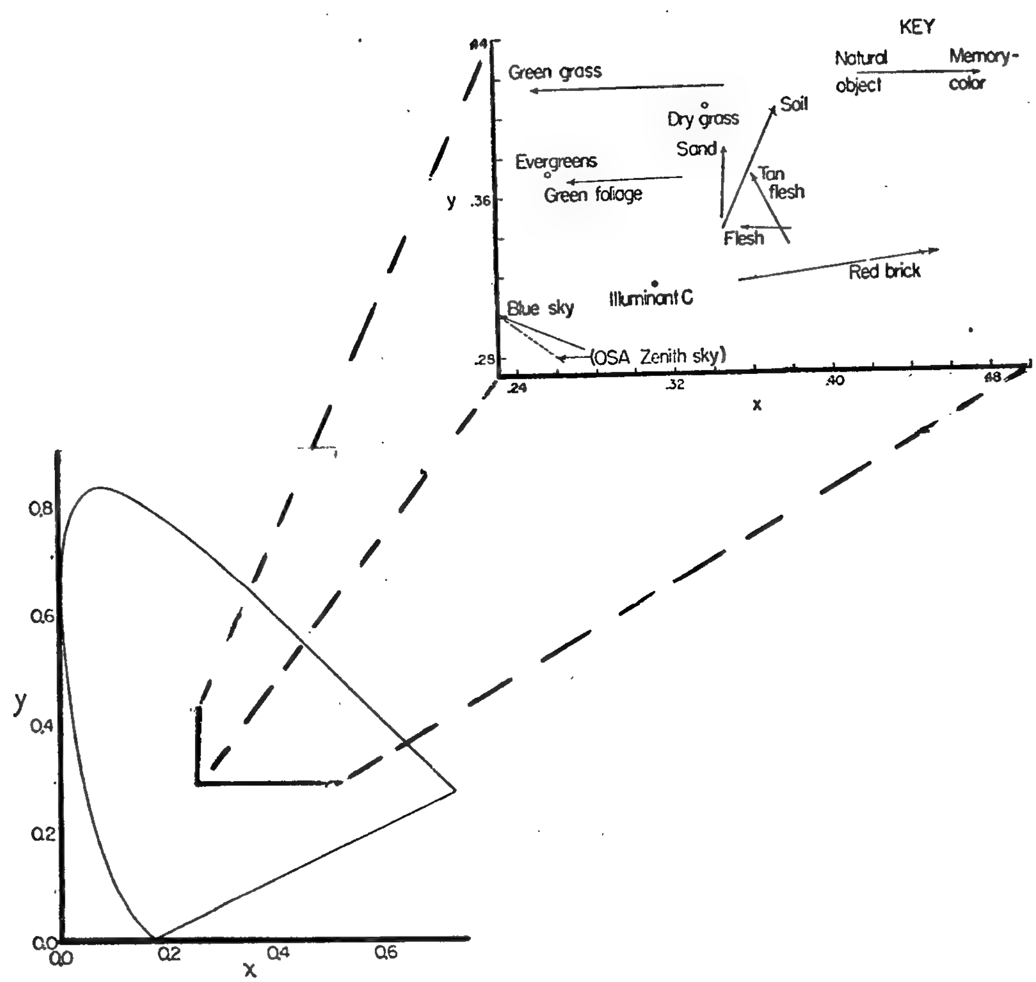

FIGURE 2.4 A COMPARISON OF THE ACTUAL AND MEMORY COLORS FOR SEVERAL FAMILIAR OBJECTS (Bartleson, 1960)

2.4 THE COLOR-NAMING CAPABILITIES OF THE AVERAGE COLOR-NORMAL OBSERVER

The color-naming ability of an average color-normal observer is a measure of his ability to identify a given color without using a reference system (i.e., using absolute judgment). An analysis of the data collected in experiments which used nearly monochromatic lights indicated that the average untrained color-normal observer can reliably name only ten to twenty basic colors without recourse to a color-reference system. Similarly, the results of experiments performed by using Munsell chips of various hue, chroma, and value have indicated that a trained and highly motivated individual could reliably name, without using a reference system, the order of fifty or more colors. The maintenance of this level of proficiency required the subject to practice approximately one hour a day naming the Munsell chips used in the experiment. Based on these results and certain theoretical considerations, it has been predicted that a trained person who had normal color vision would be able to do as well.

The analysis of this information indicates that a color vocabulary would have to be limited to fifteen to twenty words, if some kind of color-reference system were not used. A larger vocabulary, which might contain fifty or more words, would require too much time and effort to learn to use on a routine basis.

(Halsey and Chapanis, 1951; Hanes and Rhoades, 1959; Chapanis, 1965; Halsey, 1959)

2.5 A SUMMARY OF THE VISUAL PROBLEMS RELATED TO THE INTERPRETATION OF COLOR IMAGERY

The visual problems related to the interpretation of small-scale, high-quality color imagery have been discussed earlier in this section of the report. From the experimental results presented in these discussions, it is evident that under well-controlled viewing conditions, the average color-normal individual has a tremendous capacity to accurately and reliably discriminate differences between, i.e., by comparative judgment, the colors of two structure-free fields. The accuracy and precision of these judgments made by the average observer will deteriorate rapidly if the viewing conditions are not well controlled and maintained. Nevertheless, even with poorly controlled viewing conditions, the accuracy and reliability of the comparative judgments will probably be greater than his color memory or any absolute color judgments made by the same observer. However, his color memory can be improved by training and frequent practice of the exercises. On the basis of this evidence, it is concluded that a

color vocabulary which consists of more than fifteen to twenty different colors must be used with some type of visual color-reference system. Furthermore, the viewing conditions for using this visual color-reference system must be clearly specified, understood, and used. In addition, the color vocabulary must be able to designate a large number of colors because of the color-discrimination ability of the typical observer.

3.0 THE PHOTOGRAPHIC PROBLEMS RELATED TO THE INTERPRETATION OF COLOR IMAGERY

In addition to the visual problems that were discussed in Section 2.0, the type of color vocabulary that might be used by the Center will in part be determined by the photographic scale and color fidelity of the imagery. As will be discussed in Section 3.1, the photographic scale, which is the ratio of the focal length to the altitude of the acquisition system, is the acquisition parameter that determines the angular size of the image to be viewed. Thus, the photographic scale is related to the expected color-discrimination performance because, as discussed in Section 2.0, that ability is related to the angular size of the image to be viewed. The color-rendition or color-fidelity characteristics of the imagery that are used is important to the development of the color vocabulary because it helps to specify both the nature and size of the color tolerances that will be required. The color-fidelity or color-rendition problems that are related to color imagery are discussed in Section 3.2.

3.1 PHOTOGRAPHIC SCALE AND ITS RELATIONSHIP TO THE ANGULAR SIZE OF THE TARGET SEEN BY THE IMAGE INTERPRETER

Photographic scale is expressed as the ratio of the focal length to the altitude of the acquisition camera. This ratio determines the image size of the targets being photographed. For example, imagery acquired from an altitude of 10,000 feet with a 6-inch focal-length lens would have a photographic scale of 1:20,000. At this scale, the length of an image of an automobile or any other object whose ground size was 16 feet in length would be 0.0096 in or 0.240 mm.

The image size of targets is one of two factors that determine the angular size of the image seen by the image interpreter or other observer. The optical magnification of a viewing instrument such as a stereoviewer is the second factor. As would be expected, the angular size of the object being viewed increases as the observer increases the optical magnification of the viewer. The relationship between the angular size of the image, the size of the object being viewed in the imagery, and the total optical magnification of the viewing instrument can be expressed as:

$$\theta = 0.229\ MS \qquad (1)$$

where θ is the angular size of the image in degrees, M is the total optical magnification of the viewing system, and S is the dimension of the image in millimeters.

The relationship expressed in Equation (1) is summarized in the nomograph shown in Figure 3.1. The dotted line indicates the angular size of the image would be 2° if it were the image of a 6-meter (19.7-foot) ground object that had been photographed at 20,000 feet with a 6-inch lens and was being viewed at an optical magnification of 60x. Because of the linear nature of Equation (1), the image of a 5-foot object photographed and viewed under the same conditions would have an angular size of approximately one-half a degree (1/2°).

Although the angular size of the image being viewed can be increased by increasing the total optical magnification, this method is limited by the granular nature of the dye deposits which are formed in the film. It is anticipated that the granular nature of color imagery used by the Center would limit the optical magnification that could be routinely and easily used by the image interpreters to a maximum of approximately 60x. By using 60x as a working upper limit and the nomograph in Figure 3.1, it is evident that all images whose dimensions are less than 0.15 millimeters will have an angular size of less than 2 degrees.

As was discussed in Sections 2.1 and 2.2, the color discrimination and matching ability of the average color-normal individual is quite dependent upon the angular size of the colored areas that he is trying to distinguish between or match together as well as the luminance levels. A 1 to 2 degree field of view is desired for accurate and reliable color matching. At a photographic scale of 40,000:1 and viewing magnification of 60x, a 2° field of view corresponds to a ground length of approximately 20 feet, and a 1/2° field of view corresponds to a ground length of approximately 5 feet. Thus, the images of most of the targets that may be of interest to the Center will have angular sizes of less than the desired 1 to 2 degrees; therefore, a color vocabulary that might be used by the Center should not require the image interpreter to make very accurate visual color matches or to visually discriminate between a large number of nearly identical colors.

3.2 COLOR RENDITION IN THE PHOTOGRAPHIC PROCESS AND ITS RELATIONSHIP TO THE COLOR VOCABULARY

"Color fidelity" is a term used to describe the ability of a color-reproduction process to accurately reproduce the colors in

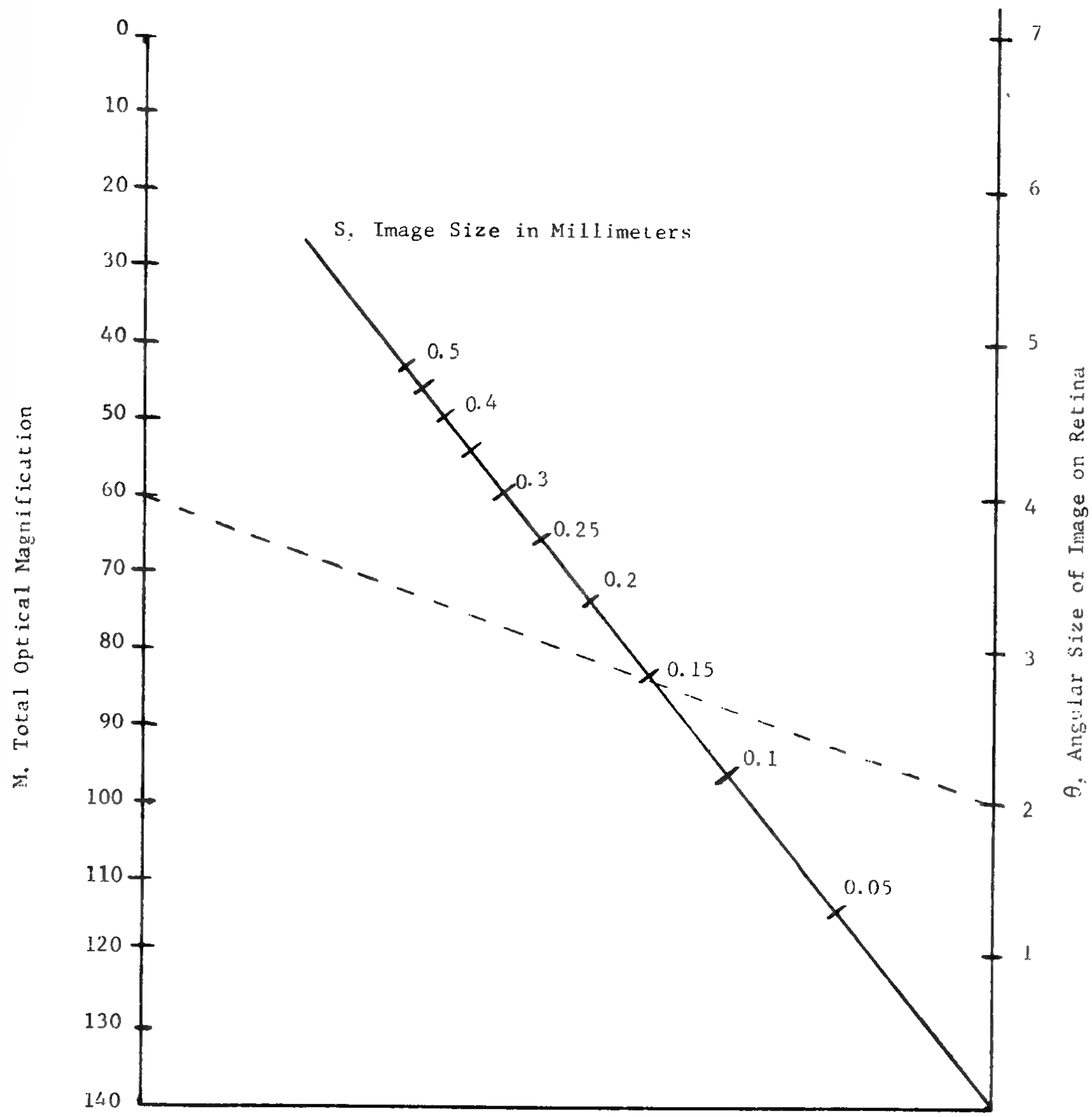

FIGURE 3.1 A NOMOGRAPH FOR DETERMINING THE ANGULAR SIZE OF AN IMAGE ON THE OBSERVER'S RETINA WHEN GIVEN THE OPTICAL MAGNIFICATION OF THE VIEWING INSTRUMENT AND THE SIZE OF IMAGE ON THE FILM

the original scene. The color fidelity of a process is sometimes assessed by using some numerical measure which is related to the size of the differences between the chromaticity coordinates of the colors in the original scene and the chromaticity coordinates of their reproduction in the imagery. Nevertheless, it should be remembered that even if the colors in the original scene have the same chromaticity coordinates as the colors in the reproduction, the colors may appear to be different because of differences in the surface textures.

The color-fidelity or color-rendering properties of a photographic process also are controlled by both the spectral sensitivity of the various layers in the conventional tripack emulsion and the spectral transmittance of the dyes that are formed during development. In technical literature there are many complete and detailed discussions of how the color fidelity of a color process is related to both the red, blue, and green sensitivity of the tripack emulsion and spectral transmittance of the magenta, cyan, and yellow dyes that are formed in the emulsion during the processing of the exposed film. However, these details of the theory as they apply to a color-reversal film such as SO-242 or SO-255 are not entirely applicable to the color vocabulary and are too complicated to discuss in this report. In general, a color process that faithfully reproduces all the colors in the scene can not be made by using real (i.e., physically realizable) dyes and spectral sensitizers. Even when the photochemist is working with real dyes and spectral sensitizers, he must compromise between the color-rendering properties of the color reproduction process and such practical considerations as resolution, shelf-life, and cost. Thus, even if there were no color degradation due to factors such as the atmospheric haze and clouds, the colors of objects seen in the imagery are, at best, only close approximations to the colors of the objects.

Color-reversal films such as SO-242 and SO-255, which are made with real spectral sensitizers and dyes, can not reproduce all the colors that appear on the CIE chromaticity diagram. The gamut of those colors that can be reproduced by the film is of importance to the development of a color vocabulary because it delineates the range of colors that must be covered by the vocabulary. Because of the tridimensional nature of color, the color gamut of a color process is defined as the volume formed by the locus of points representing the chromaticity coordinates (x, y) and the lightness value (Y) of the various colors that can be formed by specific combinations of the available amounts of the colorants used in the process. In photography, the color gamut of a film or a process is generally specified by the locus of points that represent the chromaticity coordinates of the colors formed by the various combinations of 3.0 END (equivalent neutral density) concentrations of the cyan, magenta, and yellow dyes used in the process. The expected color gamut or color

volume for SO-242 or SO-255 is shown in Figure 3.2; the projection of this color volume onto the regular 1931 CIE chromaticity diagram is shown in Figure 3.3; and the numerical values for the data plotted in Figure 3.2 and 3.3 are tabulated in Table 3.1.

Of importance to the development of the color vocabulary is how many of the colors of natural and cultural objects will have chromaticity coordinates that, when plotted on the CIE diagram, will be contained within the color gamut that has been calculated for a film such as SO-242. In Figure 3.4, the chromaticity coordinates for colors of some selected natural and cultural objects and the color gamut of SO-242 have been plotted on a 1931 CIE chromaticity diagram. These values also are listed in Tables 3.2 and 3.3. As shown in Figure 3.4, all the coordinates for the colors are contained within the color gamut of SO-242. This means that the colors of objects appearing in the imagery acquired with SO-242 will not be grossly distorted.

In addition to those inherent film problems (e.g., unstable dyes), which degrade the color fidelity of the imagery, there are many other opportunities for degrading the color fidelity of the imagery during the acquisition and processing phases of a mission. An example of the magnitude and direction of the color shifts caused by a variation in exposure is shown in Figure 3.5. For these calculations of the color shifts resulting from variations in exposure, it was assumed that the proper exposure was that which would accurately reproduce grays or achromatic colors in the scene. As is shown in Figure 3.5, an over-exposure tends to desaturate and increase the lightness of the colors, and an under-exposure tends to produce darker colors of a higher saturation. A shift in the dominant wavelength was produced by both the underexposure and the overexposure. Color shifts of an equivalent size and magnitude also can be caused by variations in atmospheric conditions and sun angle.

When the magnitude of the color shifts that are illustrated in Figure 3.5 is compared to the 10x enlarged color discrimination ellipses in Figure 2.1, it is quite obvious that very small variations in the exposure conditions will produce color shifts that are readily perceptible to the average color-normal observers. Thus, a color vocabulary that might be used by the Center must take into account the color shifts that are caused by variations in the acquisition and processing phases of a given mission. Furthermore, the color vocabulary as a means of reporting out and cataloguing target signatures must also account for the color variations that will occur on a mission-to-mission basis. Thus, color correction formulas will have to be developed.

(Bergner, Gelbke, and Mehliss, 1966; Evans, Hanson, and Brewer, 1953; Slayter, 1970; Wyszecki and Stiles, 1967; Hunt, 1967)

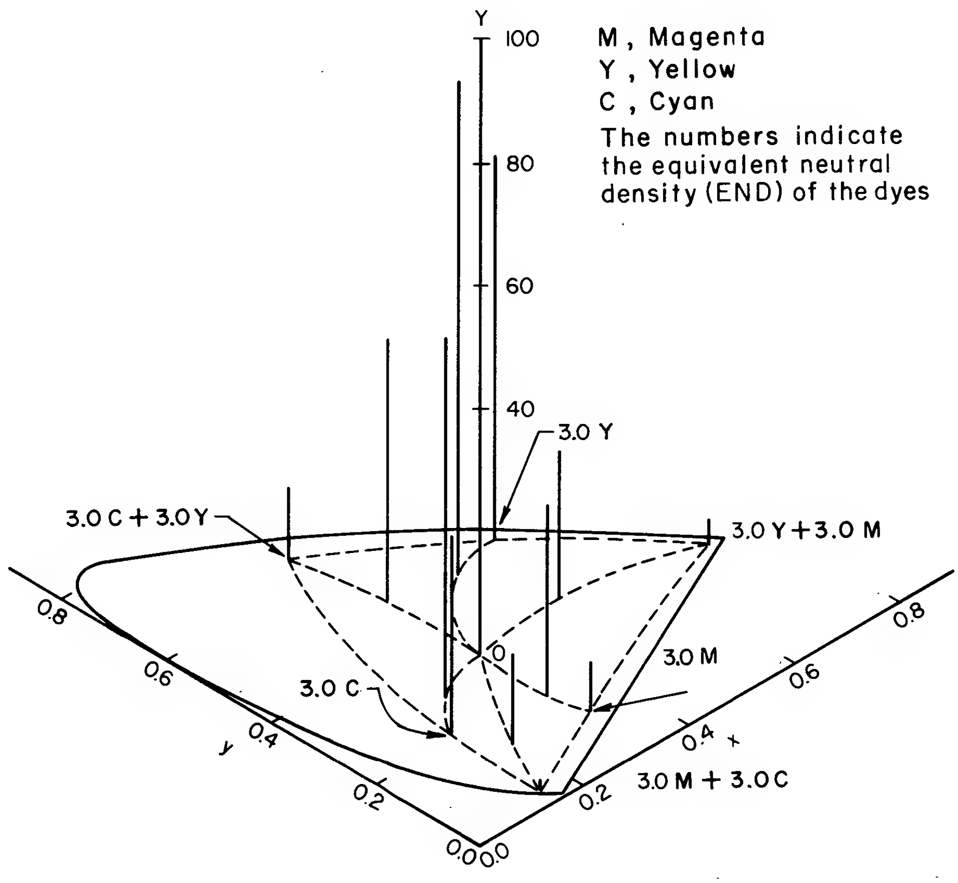

FIGURE 3.2 THE APPROXIMATE COLOR VOLUME OF EASTMAN KODAK'S SO-242 COLOR REVERSAL ACQUISITION FILM

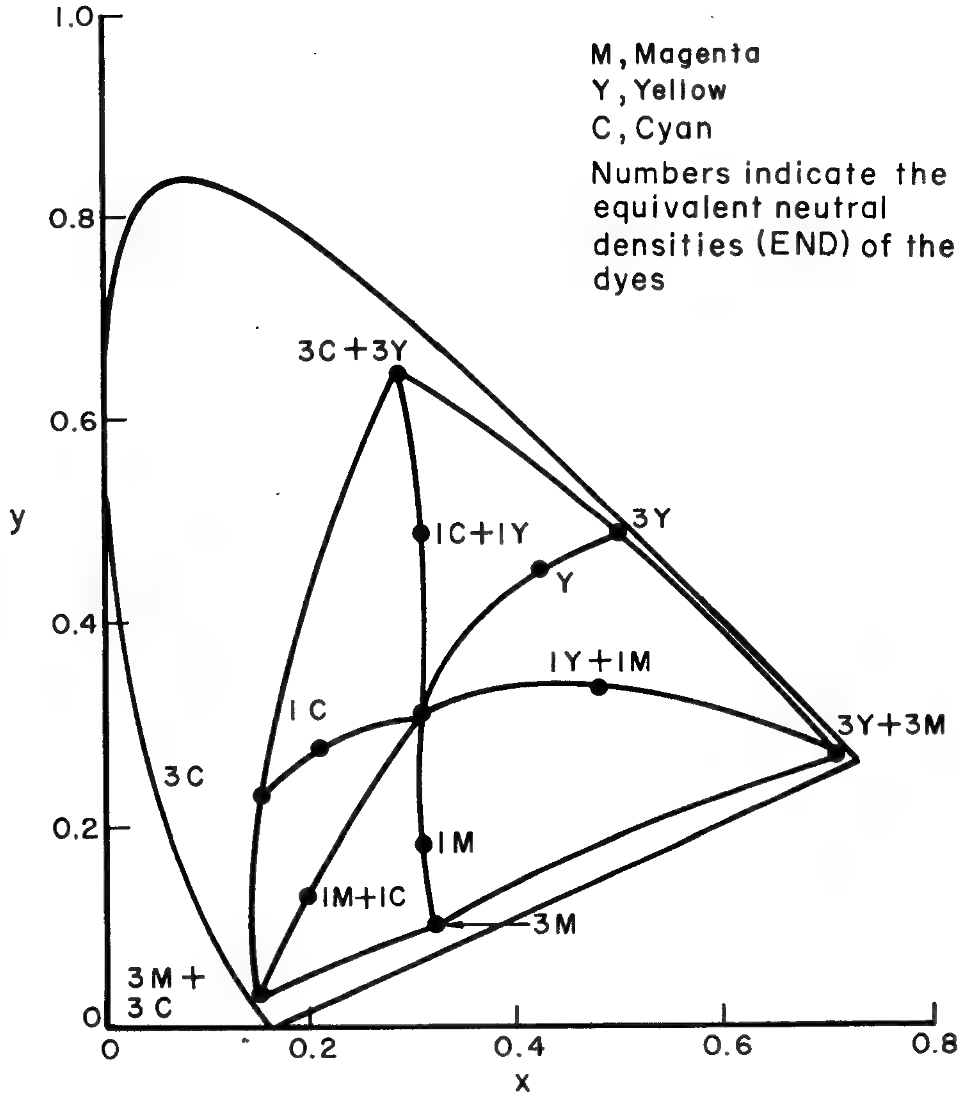

FIGURE 3.3 THE APPROXIMATE COLOR GAMUT OF EASTMAN KODAK'S SO-242 COLOR-REVERSAL ACQUISITION FILM

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TABLE 3.1 THE CIE AND MUNSELL DESIGNATIONS FOR THE APPROXIMATE COLOR GAMUT OF EASTMAN KODAK'S SO-242 COLOR REVERSAL ACQUISITION MATERIAL

Color of Dye	END	CIE x	CIE y	CIE Y	Munsell H V C
Yellow	1.0	.425	.461	.817	10Y 9/10
Yellow	3.0	.504	.485	.628	2.5Y 8/22
Cyan	1.0	.217	.281	.579	2.5B 8/10
Cyan	3.0	.157	.231	.309	5B 6/10
Magenta	1.0	.308	.188	.298	7.5P 6/18
Magenta	3.0	.320	.104	.069	10P 3/24
Cyan + Yellow	1.0	.307	.491	.439	10GY 7/10
Cyan + Yellow	3.0	.286	.653	.114	10GY 4/14
Cyan + Magenta	1.0	.195	.135	.143	7.5PB 4/16
Cyan + Magenta	3.0	.148	.029	.011	7.5PB 1/22
Magenta + Yellow	1.0	.483	.341	.253	7.5R 5/4
Magenta + Yellow	3.0	.719	.270	.047	7.5R 3/18

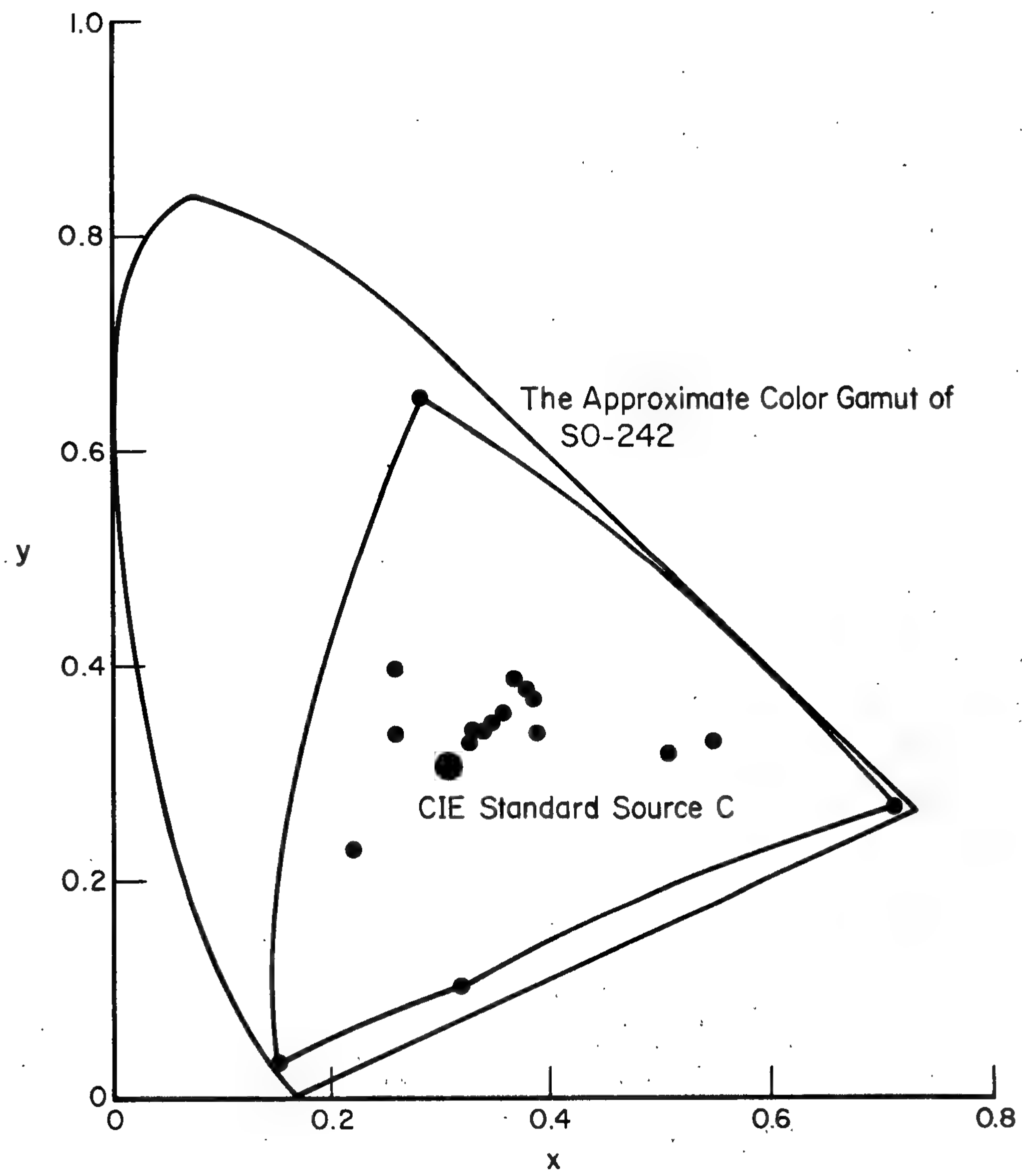

FIGURE 3.4 THE CHROMATICITY COORDINATES FOR THE COLORS OF SOME SELECTED NATURAL AND CULTURAL OBJECTS AND THEIR RELATIONSHIP TO THE COLOR GAMUT OF SO-242

TABLE 3.2 THE CIE CHROMATICITY COORDINATES, LIGHTNESSES, DOMINANT WAVELENGTHS, AND EXCITATION PURITIES FOR THE COLORS OF SELECTED NATURAL AND CULTURAL TARGETS

Type of Sample	Chromaticity Coordinates x	Chromaticity Coordinates y	Lightness Value Y, %	Dominant Wavelength λ_d nm	Excitation Purity P_e, %	CIE Standard Source
1. Inland water	0.269	0.289	5.0	481.0	31.0	B
2. Snow, fresh fallen	0.340	0.346	77.0	481.0	3.0	B
3. Snow, covered with ice	0.351	0.354	75.0	579.5	2.0	B
4. Limestone, clay	0.377	0.376	63.0	579.0	18.0	B
5. Mountain tops, bare	0.399	0.387	24.0	581.6	29.0	B
6. Sand, dry	0.399	0.387	24.0	581.6	29.0	B
7. Clay, soil, wet	0.382	0.373	9.0	582.8	18.0	B
8. Ground, bare, rich soil, dry	0.382	0.373	9.0	582.8	18.0	B
9. Ground, black earth, sand, loam	0.377	0.369	3.0	583.2	15.0	B
10. Coniferous forest, winter	0.381	0.396	3.0	574.4	25.0	B
11. Coniferous forest, summer	0.397	0.410	8.0	575.8	36.0	B
12. Meadow, dry; grass	0.397	0.410	8.0	575.8	36.0	B
13. Deciduous forest, summer	0.394	0.432	10.0	571.9	43.0	B
14. Grass, lush	0.394	0.432	10.0	571.9	43.0	B
15. Deciduous forest, fall	0.451	0.399	15.0	585.8	50.0	B
16. Field crops, ripe	0.451	0.399	15.0	585.8	50.0	B
17. Earth roads	0.377	0.369	3.0	583.2	15.0	B
18. Black top roads	0.382	0.373	9.0	582.8	18.0	B
19. Buildings	0.382	0.373	9.0	582.8	18.0	B
20. Wet White Sand, Rodger's Quarry	0.359	0.356	21.8	580.4	23.7	C
21. Wet Yellowish Quartz Sand, Rodger's Quarry	0.392	0.373	21.0	582.7	37.2	C
22. Wet Commercial (Zonalite) "Vermiculite"	0.354	0.348	16.5	582.0	20.3	C
23. Dry White Sand, Rodger's Quarry	0.350	0.349	37.7	580.3	19.5	C
24. Dry Yellowish Quartz Sand, Rodger's Quarry	0.373	0.363	36.9	581.6	29.4	C
25. Dry Commercial (Zonalite) "Vermiculite"	0.337	0.337	27.7	580.0	13.0	C
26. Damp Collington Sandy Loam	0.349	0.345	14.9	582.0	18.0	C
27. Outer Bark, Scrub Pine (Pinus virginiana, Mill.)	0.358	0.346	11.9	584.2	20.8	C
28. Inner Bark, Scrub Pine (Pinus virginiana, Mill.)	0.372	0.349	14.7	586.4	25.4	C

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TABLE 3.2 THE CIE CHROMATICITY COORDINATES, LIGHTNESSES, DOMINANT WAVELENGTHS, AND EXCITATION PURITIES FOR THE COLORS OF SELECTED NATURAL AND CULTURAL TARGETS (Continued)

Type of Sample	Chromaticity Coordinates x	Chromaticity Coordinates y	Lightness Value Y, %	Dominant Wavelength λ_d nm	Excitation Purity P_e, %	CIE Standard Source
29. Outer Bark, White Oak (Quercus alba, L.)	0.326	0.342	27.7	571.1	11.1	C
30. Inner Bark, White Oak (Quercus alba, L.)	0.357	0.350	7.5	580.2	23.1	C
31. Chinese Red #6335 Chi-namel Paint, Chi-namel Paint and Varnish Co.	0.556	0.330	16.5	609.4	69.5	C
32. Colony Yellow #317 House Paint, Lowe Brothers	0.379	0.391	68.5	576.5	38.4	C
33. Green #173 Tractor Paint, Lowe Brothers	0.268	0.339	6.8	497.6	14.2	C
34. Red #139 Tractor Paint, Lowe Brothers	0.514	0.321	10.7	613.2	55.8	C
35. Royal Blue Permanent Trim Paint, John W. Masury & Son	0.221	0.234	10.0	478.8	41.6	C
36. Seal Brown Supreme House Paint, John W. Masury & Son	0.378	0.343	8.2	590.3	25.4	C
37. Verdi Green #6830 Super House Paint, Chi-namel Paint and Varnish Co.	0.256	0.400	30.7	511.1	18.6	C
38. Khaki #1 (cotton)	0.368	0.366	24.7	579.7	28.9	C
39. Olive Drab #52 (wool)	0.378	0.379	10.3	578.6	35.1	C
40. US Marine Corps Necktie	0.371	0.362	19.9	581.6	28.5	C
41. US Marine Corps Overseas Cap (summer)	0.377	0.371	19.0	580.4	32.7	C
42. US Marine Corps Pants (summer)	0.368	0.364	21.6	580.3	28.3	C
43. US Marine Corps Shirt (summer)	0.368	0.372	23.2	578.2	30.4	C
44. US Marine Corps Overseas Cap (winter)	0.329	0.345	5.4	572.0	12.8	C
45. US Marine Corps Blouse (winter)	0.327	0.347	5.3	569.7	12.8	C
46. US Marine Corps Pants (winter)	0.329	0.344	6.0	572.3	12.5	C

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TABLE 3.3 THE MUNSELL AND ISCC-NBS DISIGNATIONS FOR THE COLORS OF SELECTED NATURAL AND CULTURAL TARGETS

Type of Sample	Hue	Value/Chroma	ISCC-NBS Color Designations
20. Wet White Sand, Rodger's Quarry	0.2Y	5.2/2.3	Grayish yellowish brown
21. Wet Yellowish Quartz Sand, Rodger's Quarry	8.6YR	5.1/3.7	Moderate yellowish brown
22. Wet Commercial (Zonalite) "Vermiculite"	9.2YR	4.6/1.8	Grayish yellowish brown
23. Dry White Sand, Rodger's Quarry	9.8YR	6.6/2.2	Light grayish yellowish brown
24. Dry Yellowish Quartz Sand, Rodger's Quarry	8.9YR	6.6/3.6	Light yellowish brown
25. Dry Commercial (Zonalite) "Vermiculite"	9.0YR	5.8/1.3	Light grayish yellowish brown
26. Damp Collington Sandy Loam	9.6YR	4.4/1.5	Grayish yellowish brown
27. Outer Bark, Scrub Pine (Pinus virginiana, Mill.)	8.0YR	4.0/1.7	Grayish yellowish brown
28. Inner Bark, Scrub Pine (Pinus virginiana, Mill.)	5.6YR	4.4/2.5	Grayish brown
29. Outer Bark, White Oak (Quercus alba, L.)	0.9GY	5.8/1.1	Light olive gray
30. Inner Bark, White Oak (Quercus alba, L.)	9.7YR	3.2/1.5	Dark grayish yellowish brown
31. Chinese Red #6335 Chi-namel Paint, Chi-namel Paint and Varnish Co.	7.2R	4.6/13.3	Vivid Reddish orange
32. Colony Yellow #317 House Paint, Lowe Brothers	3.7Y	8.5/5.1	Light yellow
33. Green #173 Tractor Paint, Lowe Brothers	0.8BG	3.1/2.9	Dark bluish green
34. Red #139 Tractor Paint, Lowe Brothers	5.9R	3.8/9.8	Moderate red
35. Royal Blue Permanent Trim Paint, John W. Masury & Son	2.1PB	3.7/5.6	Moderate blue
36. Seal Brown Supreme House Paint, John W. Masury & Son	3.3YR	3.3/2.3	Grayish brown
37. Verdi Green #6830 Super House Paint, Chi-namel Paint and Varnish Co.	5.5G	6.1/8.6	Brilliant green
38. Khaki #1 (cotton)	1.2Y	5.5/2.8	Light olive brown
39. Olive Drab #52 (wool)	3.0Y	3.7/2.8	Moderate olive brown
40. US Marine Corps Necktie	9.5YR	5.0/2.7	Grayish yellowish brown
41. US Marine Corps Overseas Cap (summer)	0.8Y	4.9/3.0	Grayish yellowish brown
42. US Marine Corps Pants (summer)	0.6Y	5.2/2.7	Grayish yellowish brown
43. US Marine Corps Shirt (summer)	3.0Y	5.4/2.8	Light olive brown
44. US Marine Corps Overseas Cap (winter)	0.1GY	2.7/0.8	Olive gray
45. US Marine Corps Blouse (winter)	1.8GY	2.7/1.0	Olive gray
46. US Marine Corps Pants (winter)	10.0Y	2.9/0.9	Olive gray

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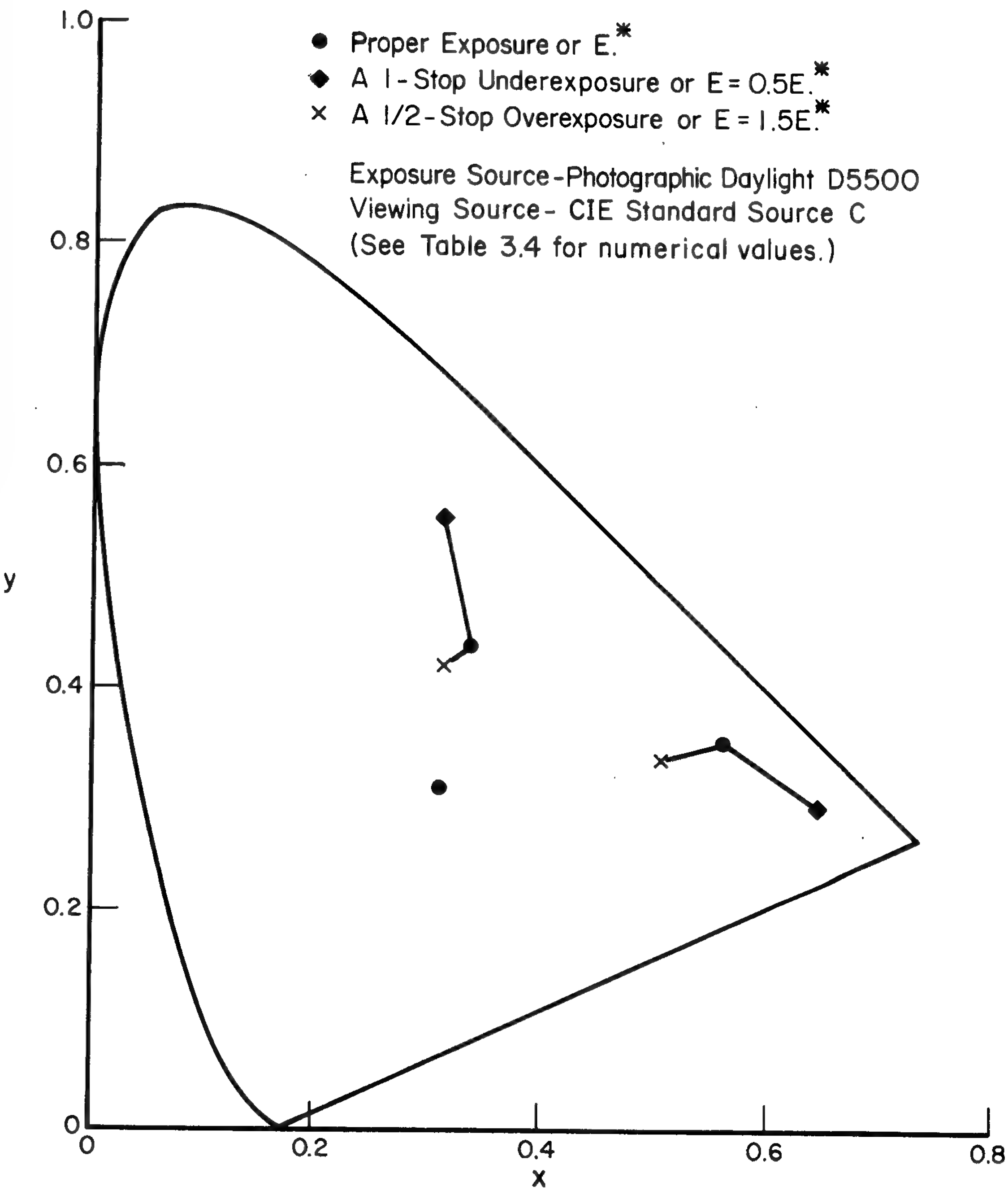

FIGURE 3.5 THE MAGNITUDE AND DIRECTION OF THE COLOR SHIFTS PRODUCED ON SO-242 BY DIFFERENT EXPOSURE CONDITIONS

TABLE 3.4 THE CIE CHROMATICITY COORDINATES FOR THE RED AND GREEN TARGETS WHOSE IMAGES WERE EITHER PROPERLY EXPOSED, OVEREXPOSED, OR UNDEREXPOSED DURING ACQUISITION

Color of the Target and Exposure Conditions	Chromaticity Coordinates* x	Chromaticity Coordinates* y	Lightness Value*, percent Y
Green target-correct exposure	0.34	0.44	36
Green target-1 stop underexposure	0.31	0.56	13
Green target - 1/2 stop overexposed	0.31	0.42	47
Red target-correct exposure	0.57	0.35	12
Red target-1 stop underexposure	0.65	0.29	4
Red target-1/2-stop overexposure	0.51	0.34	17

* CIE Illuminant C.

3.3 A SUMMARY OF THE PHOTOGRAPHIC PROBLEMS RELATED TO THE INTERPRETATION OF COLOR IMAGERY

Some of the photographic problems of small-scale color imagery, which were considered to be relevant to the color vocabulary, have been discussed in this section of the report. Images of targets expected to be of interest to the Center would have an angular size of less than two degrees when viewed at the maximum useable magnification. Fields of view whose angular sizes are the order of two degrees or larger are considered necessary for accurate and reliable color matching or color discrimination. Therefore, it is concluded that because of the small angular size of the targets of interest it will be difficult to use a visual matching technique to reliably determine the colors of an image.

The color fidelity of imagery acquired by using acquisition films such as SO-242 or SO-255 has also been discussed. It was stated that the color fidelity or color-rendering properties of color reversal films such as SO-255 or SO-242 were degraded because the photochemist also had to consider factors such as resolution, dye stability, and cost in his selection of the sensitizers and the colorants. It was shown in Section 3.1 that noticeable color shifts or color variations can result from small changes or variations in exposure. Similarly, color shifts of the same magnitude can be expected for variations in other acquisition factors such as sun angle and atmospheric conditions over the target. It is apparent from these results that, at best, the image colors will be only close approximations to the actual or "ground-truth" colors of these objects. It also is apparent that the image colors of an object will vary on a mission-to-mission basis if not on a frame-to-frame basis. Thus, any accurate measurement of the image color will be only an approximation to the actual color. It is concluded that any color vocabulary that might be used by the Center must be capable of accounting, in some way, for these variations in the image color of a target if the actual color is to be determined. Furthermore, the ground-truth color of a target can not be determined solely from the information that can be extracted from the imagery because both the photography and color are integrating processes. To determine the actual color of an object, the image interpreter or photoscientist must use some type of an acquisition model which includes and accounts for such variables as sun angle and atmospheric effects. Hence, one of the outputs of the color vocabulary should be color-related data that can be used as an input to an acquisition model which would be used to determine the actual color of the object.

4.0 THE MISSION OF THE CENTER AND THE FUNCTION OF ITS PERSONNEL

The Center is an operational organization whose mission is to transform information in the form of photographic images into words and numbers that can be used by other individuals and organizations. Because of the operational nature of the Center, the speed and accuracy with which it fulfills its assigned mission is of primary importance. To aid in the fulfillment of this mission, the Center has become a highly self-contained and self-sufficient organization employing people with a great diversity of backgrounds and skills. Thus, any color vocabulary that is going to be used successfully by the Center must be applicable to most of the job-related color needs of a very diversified group of individuals.

To aid in the development of the color vocabulary, a very simple job analysis was performed to delineate the anticipated job-related color needs of the various members of the staff who might be involved in all or some aspects of any future exploitation of color imagery. The anticipated needs were determined by examining what the staff now does to aid in the exploitation of conventional black and white imagery and what it might be expected to do to assist in the exploitation of color imagery. The observations and conclusions of this simplified job analysis are discussed in the following sections. The significance of these job-related problems to the development of the color vocabulary is considered in Section 6.0.

4.1 THE PERSONNEL OF THE CENTER AND THEIR ANTICIPATED COLOR VOCABULARY RELATED PROBLEMS

4.1.1 Image Interpreters

In the exploitation of conventional black and white imagery, the image interpreter has two principal funtions: (1) the identification and enumeration of specific and known targets, and (2) the detection of any changes or new activity in his sector that might be of interest to the analyst. The image interpreter must accurately perform these two principal tasks under the pressure of a very demanding time schedule. It is anticipated that the possible future use of color imagery will not significantly modify the nature or content of these two principal requirements. It is expected that color imagery will require the image interpreter to name or, in some other way, read out the colors of certain targets for which he is responsible and to search for particular colors that may be of value to the analyst. At the present time, however, the analysts and other users of the information have specified neither what kind of color-related information they need nor what form would be most useful.

4.1.2 Collateral Researchers

The primary function of the collateral researchers at the Center is clerical. In addition to some editing responsibilities, the collateral researchers obtain, distribute, and collect the forms used for compiling the information being reported by the image interpreters. Except for the addition of some new color-related terms or new color-reporting forms, it is anticipated that the use of color imagery would not significantly alter the clerical functions of the collateral researcher. Nevertheless, the possible use of color imagery would require the collateral researchers to search, collect, and catalog color-related information about the targets or other objects located in their geographical sector of responsibility. This means that they would need to understand the color vocabulary used by others.

4.1.3 Editors

The editors at the Center check and correct the format and style of the written material that is submitted for publication by members of the staff. The major portion of an editor's time is spent in editing the material submitted by the image interpreters. Because of the nature of the first-phase reports, it is anticipated that any possible future use of color photography will not significantly modify this part of the editor's job. Nevertheless, the possible use of color imagery could lead to the writing of second- and third-phase reports that contain a considerable amount of color-related information. To edit this type of material, some of the editors would have to acquire an understanding of the color vocabulary used by the Center.

4.1.4 Model Makers

The model makers at the Center design and build detailed scale models of the various targets that have appeared in the imagery. These models are used as visual aids for presentations such as formal briefings and to aid the interpreters in their study of particular ground objects or targets. It is interesting to note that the model makers are already building colored models even though most of the data they use for their construction has been acquired from black and white imagery. The major problem that might be experienced by the model makers if color imagery were to be used would be in making the colors of the model duplicate what the interpreter sees in his viewer. This problem would be caused by the

difference in the texture of the color material rather than by differences in the hue, saturation, and lightness of the two colors. It is clear, however, that, to enable the model makers to duplicate the actual color of the target, accurate color information will be required through the use of a precise visual color reference system.

4.1.5 Librarians

The librarians at the Center perform the same job tasks (e.g., cataloguing, indexing, etc.) that are done by the librarians in any technical library. The use of color imagery should neither significantly modify nor add to the tasks currently performed. However, it might be necessary for the librarians to increase the scope of their present indexing methods so that the catalogue cards would include some comments or notations for those library materials that contained color-related information. In general, it is believed the librarians will need a very simple color vocabulary that would contain limited numbers of color-related words and terms.

4.1.6 Scientists and Engineers

The scientists and engineers at the Center direct the research and development of concepts, techniques, and equipment that will aid in the exploitation of imagery. The use of color imagery has had and will continue to have a significant impact on the tasks performed by these engineers and scientists. They will have to be fully aware of all aspects of color and its relationship to the exploitation of color imagery. Furthermore, it is expected that the use of color imagery will necessitate these people being aware of the job-related color needs of others at the Center so that they can provide advice and assistance to these individuals. The scientists and engineers will need a vocabulary that is both unlimited and accurate.

4.1.7 Artists and Illustrators

The artists and illustrators at the Center produce drawings, sketches, and other types of visual presentation materials at the request

of various members of the staff. These visual materials that are prepared are used for both oral and written reports. Most of these drawings are intended to aid in the explanation of a concept rather than to be exact renditions of actual objects. At the present time the artists and illustrators select colors only for visual emphasis and aesthetic qualities. However, it is anticipated that the use of color imagery will not significantly modify the color-related aspects of their jobs. If exact rendition is ever needed, the artists and illustrators will need to understand the vocabulary of the requester who, in turn, will need to furnish a color-reference sample.

4.1.8 Photographic Technicians

The term "photographic technician" describes all those individuals at the Center who are involved in the making of continuous tone prints and transparencies, which are used for briefing boards and reports, and halftone transparencies, which are used by the printing shop. It is anticipated that the use of color photography will increase the color-related job problems for this group at the Center. For example, the processing of color films and papers takes considerably more time and is more complex than the processing of silver halide-based black and white films and papers. In most of these cases, the specialized photographic vocabulary of the technician will be adequate. Nevertheless, a problem the photographic technician might have is clearly communicating with the individual who initiates the request for color prints and transparencies. If the image interpreter wants a print that emphasizes the red color in the picture, then he and the photographic technician must clearly agree on how much emphasis the reds are to receive and how large a shift in the overall color balance of the print is to be tolerated in achieving the requested emphasis. In this case, some type of a visual color reference system will be required.

4.1.9 Printers and Pressmen

As might be expected by their title, the printers are responsible for the printing, collating, trimming, and binding of reports published by the Center. The future use of color photography at the Center may have a major impact on the job-related color needs of the printers. Previously, the color printing that was done at the Center was two and three-color printing with flat inks rather than four-color printing that uses process inks to create a full gamut of colors. As a result of the recent introduction of four-color printing at the Center, some of the printers

in the print shop will need to understand the principles of the subtractive color process, as well as certain color-related printing problems such as ink trapping and dot gain. In those situations where accurate color reproduction is required, the printer will need to use color-reference samples to visually check the quality of the reproductions.

4.1.10 Photogrammetrists

The primary function of the photogrammetrists at the Center is the accurate and precise mensuration of the images of targets and objects whose spatial dimensions are of interest and of use to the image interpreters and analysts. The use of color imagery is expected to have more of an effect on how the photogrammetrists perform their various mensuration tasks rather than the tasks themselves. For example, the specific color of the image of an object or target whose spatial dimensions are to be determined should not create a major communication problem between the photogrammetrists and the image interpreters because the present method could be used which requires the image interpreter to set the cross-hairs of the comparator on a target and say "That's the target I want measured". The real color-related job needs of the photogrammetrists are anticipated to be related to the development of techniques for the mensuration of color imagery. In this latter situation, they will need to understand concepts such as hue, saturation, and lightness, and color-related terms such as cyan, magenta, and yellow. Of importance to the photogrammetrist will be the visual problems (e.g., Mach bands and simultaneous color contrast) that are related to the perception and mensuration of color images.

4.1.11 Managers

The job-related color needs of the individuals in management positions are as varied as the activities of the Center. The use of color imagery by the Center could cause a significant modification in the activities of some managers. In most cases, however, the needs of the individual managers at the Section or Branch level will correspond to the color vocabulary needs of the individuals who work in these organizational units. For example, the Branch Chief who manages scientists and engineers who are directing the research and development of new image exploitation equipment will need a fairly comprehensive understanding of the psychophysical nature of color and the vocabulary used by his associates. The job-related color needs of managers above the Branch level cannot be so easily identified. At this time, it is anticipated that they will need to know only the general concepts of color and the terminology used to describe these concepts.

5.0 DISCUSSION AND INITIAL EVALUATION OF VARIOUS COLOR SYSTEMS

The third aspect of this investigation was a study of some of the existing color systems that might be used as the basis for the recommended color vocabulary. The purpose of all color systems is to designate the differences between colors in terms of a standardized set of words or numbers or some combination of these words and numbers. Some of the color systems that were investigated had been developed for very specialized purposes, whereas some of the color systems could be applied to a variety of color-naming or color-designing problems. Each of the selected systems was reviewed and studied to determine its applicability to the anticipated future color needs of the Center. To cast each system into its proper perspective, four major points were investigated for each major color system:

(1) The basic concept of the system

(2) The way the system might be applied

(3) The advantages of the system in terms of the anticipated needs

(4) The disadvantages of the system in terms of the anticipated needs.

5.1 COLOR SYSTEMS

5.1.1 The Munsell Color System

5.1.1.1 The Concept and Description of the Munsell Color System

The Munsell Color System is an orderly arrangement of a series of colored plaques or chips whose colors were selected so that perceptually there are nearly equal intervals between adjacent chips. In keeping with the tridimensional nature of color, the Munsell chips are usually arranged in the cylindrical pattern shown in Figure 5.1. In this color-order system, the term Hue is used to denote that attribute of color described by words (like red, blue, and green) and is specified in the Munsell system by capital letters (R, B, and G). Each major color sector in the Munsell System is subdivided into smaller parts which are labeled with a numerical designation. For example, 6Y would be used to label the sixth division of the yellow sector of the Munsell space. The lightness or darkness of different colors in this system is designated by the term Value. A Munsell Value of 0 on

the vertical axis in Figure 5.1 represents a black whereas a Munsell Value of 10 at the top of the same axis represents white. Various shades of gray and the lightness or darkness of a neutral color are designated by the Munsell Values between these two extremes. For example, a Munsell Value of 7 is used to specify a light gray color. The term Chroma in the Munsell color system is used to specify the saturation of the color or how much that particular color differs from a neutral gray of the same lightness. For example, the Chroma range of a color with a hue of 2YR and value 6 varies from a light brownish-gray (a Chroma of 1) to a vivid orange (a Chroma of 14).

5.1.1.2 The Application of the Munsell Color System

The Munsell designation for the color of an object in a backlighted color transparency would be determined by an image interpreter visually selecting the frontlighted Munsell chip that was the nearest visual match to the color of the object. For example, the Munsell chip that might be the nearest visual match for the color of a light blue car would have the Munsell designation of 9B 6/8 (i.e., Hue Value/Chroma). If the Munsell color system were used, it is anticipated that some type of special eye piece or viewing equipment would be used so that the image interpreter could view simultaneously the backlighted color transparency and the frontlighted Munsell chips.

5.1.1.3 The Advantages of the Munsell Color System

The principal advantage of the Munsell color system is that it is based on the visual rather than the physical aspects of color and color perception. The dimensions of the Munsell color system, Hue, Chroma, and Value, have direct correlations to the perceptual aspects of color, hue, saturation, and lightness. It is anticipated that the staff would have little difficulty in learning to understand and to use the concepts embodied in this system. Another advantage of this system is that the designation for a color can be readily transformed to the corresponding CIE numerical designation for the color. This is an advantage because the CIE system is based on the physical aspects of color and color perception which are the spectral distribution of light sources and the spectral reflectance or transmittance of a sample.

5.1.1.4 The Disadvantages of the Munsell Color System

A disadvantage of the Munsell Color System in its present form is that the observer is required to make a visual color match between a

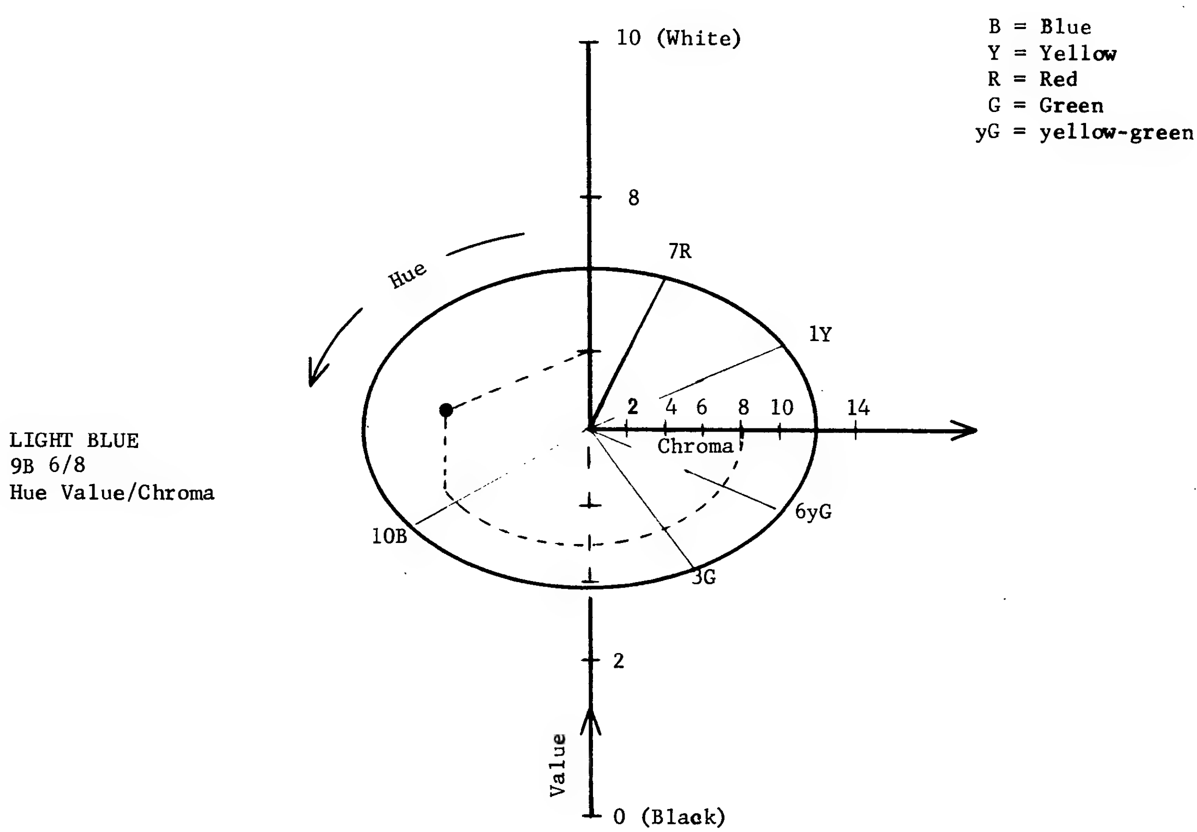

FIGURE 5.1 THE CONCEPT OF THE MUNSELL COLOR SYSTEM

frontlighted Munsell color chip and a backlighted dye image. The viewing conditions must be controlled carefully and the color-matching procedures must be specified clearly if the color-matching procedure is to produce accurate and precise results on a day-to-day and an observer-to-observer basis. Another disadvantage of the Munsell color system is that it has a limited color gamut. Although the color coordinates for the colors of both natural and cultural objects are contained within the Munsell system, the theoretical gamut of an acquisition material such as SO-242 or SO-255 is much larger than that of the Munsell chips. Thus, it would be quite possible to record on the film colors whose chromaticity coordinates were outside the Munsell system. Both of the disadvantages listed above could be minimized if not eliminated by using a set of dye-colored transparent Munsell chips whose gamut could equal or exceed that of the acquisition material. However, dye-colored transparencies may shift in color with age.

(Judd and Wyszecki, 1963; Wyszecki and Stiles, 1967; Evans, 1948; Billmeyer and Saltzman, 1966; Newhall, Nickerson, and Judd, 1943)

5.1.2 CIE Color System

5.1.2.1 The Concept and Description of the CIE Color System

The CIE (Commission Internationale de l'Eclairage) color system is based on the physical aspects of light and color perception. This system has found widespread use in the scientific and technical community. Furthermore, the CIE system makes use of the spectral reflectance or transmittance of colored materials. These properties of colorants (i.e., dyes and pigments) are closely related to their physical structure, a subject of much interest to the color scientist.

It was recognized, possibly as early as Newton's time, that most colors projected onto a white screen could be visually matched by projecting varying amounts of red, blue, and green light from three other projectors onto a common area of the same screen. As more experiments were performed, it was discovered that individual observers who had normal color vision required approximately the same amounts of red, blue, and green light to achieve a match. To standardize color-matching procedures and to help the people who were communicating with each other about color, a group of scientists met on behalf of the CIE and examined the color-matching data that had been collected. All of these color-matching data were statistically adjusted and then used to define a new set of color-matching functions for the standard observer. These color-matching functions ($\overline{x}$, $\overline{y}$, $\overline{z}$) are shown in Figure 5.2.

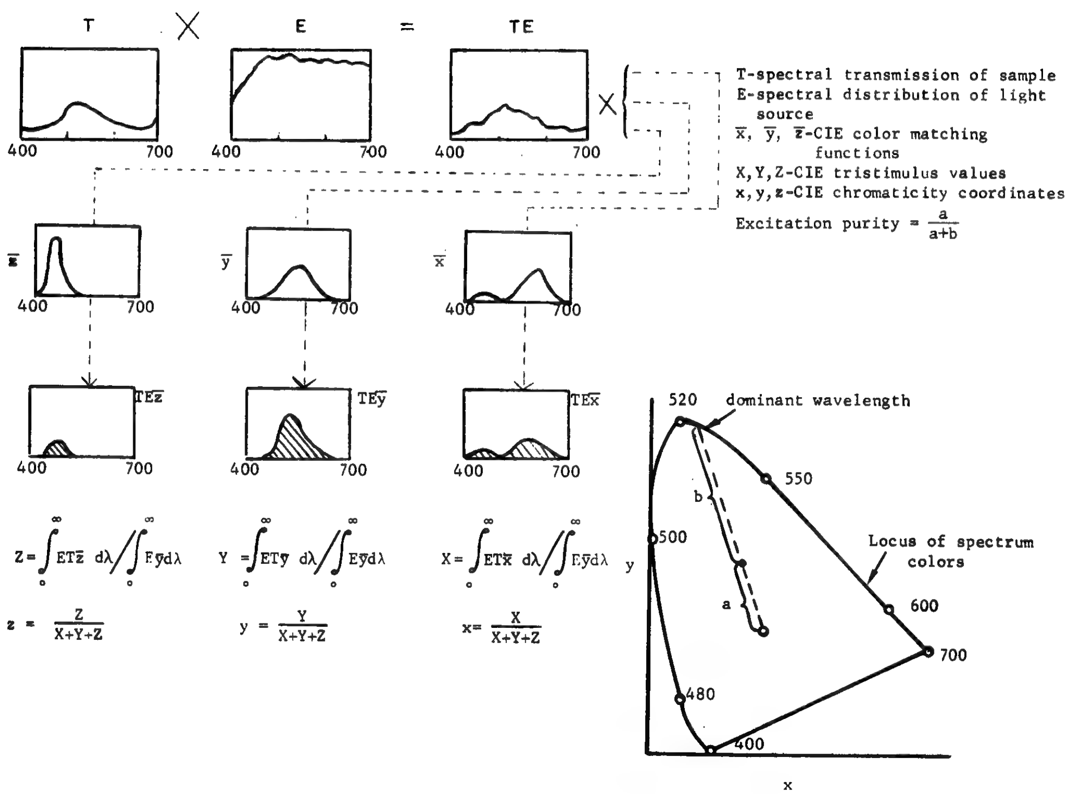

FIGURE 5.2 THE CIE COLOR SYSTEM

Approved For Release 2003/05/14 : CIA-RDP78B04560A007300010029-7

In addition to specifying the color-matching functions for the standard observer, the scientists also defined the spectral distributions for a set of standard light sources. These definitions are important because the apparent color of a sample changes as the spectral distribution of the light illuminating the sample changes. The other factor that determines the color of an object is its spectral transmittance or reflectance. Thus, the CIE designation for a color can be calculated by combining the color-matching properties of the standard observer, the spectral distribution of the standard source, and either the spectral transmittance or the reflectance of the object.

The first calculation to be performed in determining the CIE designation of an object is to form the product of T, the spectral transmittance (or R, the spectral reflectance) of the object and E, the spectral distribution of the standard source being used. A pictorial demonstration of the results of this operation being performed for a transparent object is shown at the top of Figure 5.2. A new product is then formed by multiplying the initial result TE times $\bar{x}$, $\bar{y}$, and $\bar{z}$, the color-matching functions. The curves representing the results of forming these three new products ($TE\bar{x}$, $TE\bar{y}$, $TE\bar{z}$) are shown at the end of the dashed line in Figure 5.2. The area enclosed between the curved lines and the horizontal axis is the quantity of interest in these three graphs and it is calculated by using standard numerical integration techniques. The areas under these three curves are proportional to the CIE tristimulus values that are denoted by the capital letters X, Y, and Z and are used in the formulas listed at the bottom of Figure 5.2 to calculate the CIE chromaticity coordinates, x, y, and z. The CIE color system is designed so that the sum of the values for x, y, and z is always equal to 1; therefore, it is only necessary to plot two of the coordinates - by convention, x and y - on the CIE diagram shown at the bottom right of Figure 5.2. The third dimension of the CIE color space is represented by the tristimulus value Y and is called the lightness value of the color. There are two other terms used in the CIE system. The dominant wavelength (λ_d) of a color is represented by that point at which the locus of spectrum colors or the outer boundary of the CIE diagram is intersected by a line formed by connecting the points on the CIE diagram representing the color of the object and the color of the CIE illuminant being used. The CIE excitation purity (p_e) of a color is a measure of how far the point representing a color is from the point representing the color of the CIE source being used. The CIE color system is based on the characteristics of the standard observer, a given light source, and the reflectance or transmittance of objects being measured. However, in some cases, the numerical CIE designation can be related to the visually perceived aspects of color (hue, saturation, and lightness) by using the terms such as lightness, dominant wavelength, and excitation purity.

5.1.2.2 The Application of the CIE Color System to Color Imagery

There are two methods that could be used by the Center to determine the CIE chromaticity coordinates (x, y), lightness value (Y), excitation purity (p_e), and the dominant wavelength (λ_d) for the colors of targets in the imagery. The simplest, but least accurate, method would be to use a tristimulus colorimeter whose readings would be proportional to the CIE tristimulus values (X, Y, Z). The chromaticity coordinates (x, y) for the colors of objects that were measured with a tristimulus colorimeter could be calculated by several methods. The complexity of the methods used to calculate the chromaticity coordinates could range from a simple manual method to a completely automated and computer-assisted method of calculation.

The second method that could be used to assist in determining the CIE color designations (x, y, Y, p_e, λ_d) would require that the optical transmission of the target or area of interest be measured at many wavelengths throughout the visible spectrum. These spectral transmittance values could be measured by having the image interpreter or photoscientist use some type of micro-spectrophotometer. As explained in Section 5.1.2.1, these values for the spectral transmittance must be combined with the appropriate CIE color-matching functions and spectral distribution of a CIE standard source before the tristimulus values (x, y, z) can be calculated.

These numerical calculations and manipulations are so tedious that some type of automated data reduction and computation method would have to be used if the CIE method were used.

5.1.2.3 The Advantages of the CIE Color System

The principal advantage of the CIE system is that it is based on a standardized observer and on the physical aspects of color and color perception. The use of the color-matching properties of a standardized observer means the CIE designations are independent of the color-matching capabilities of the individual making the color determinations or measurements. Because the CIE designations are determined by using the results of calculations for which the values of the spectral transmittance of filters and the spectral distribution of sources are used, the system can be used to predict the magnitude and direction of color shifts resulting from variations in the optical properties of the colored sample or light source.

Another advantage of the system is that the color gamut of SO-242 lies within the boundaries of the CIE chromaticity diagram. Thus, the chromaticity coordinates can be calculated and plotted for any color that can be reproduced by SO-242 or similar acquisition materials.

Another advantage of the CIE system is that is is continuous. For example, in color imagery, such as might be acquired with SO-242, the color of the water in a swimming pool which has a sloping bottom changes gradually from a very desaturated light blue to a moderately saturated blue or blue-green. This gradual and continuous gradation of the color of water with either depth or temperature is evident in imagery that contains targets such as beaches and large industrial cooling ponds. By using the CIE system, the image interpreter or photoscientist could specify a unique set of chromaticity coordinates for the colors of objects at any point in a given frame.

On the other hand, the CIE system can be used to determine an area weighted or an averaged color for such things as stockpiled materials and field crops.* As the wind blows across a field of grass, the leaves of grass bend back and forth so that the sunlight is reflected from them at different angles; thus, the color of the field changes. Because colored imagery represents the colors of the target at a given instant of time, the color of the crop at one end of the field might be different from the color of the same crop at the middle or other end of the field. Similarly, the color of stockpiled materials such as sand or gravel could vary because the moisture content might be different at various points. To calculate an area-weighted or an averaged color, the light from the entire area of interest could be collected and optically mixed or optically integrated before the light entered a device to determine the spectral transmittance. The capability of calculating an area-averaged color would be important in some cases because the development of a catalogue of color-related target signatures could be based on an average of these area-weighted values for the colors of objects that are acquired on a mission-to-mission basis.

5.1.2.4 The Disadvantages of the CIE Color System

The main disadvantage of the CIE system is that it requires the image interpreter or photoscientist to use some type of equipment to

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* Although techniques for determining an area-weighted or area-averaged color could be developed for all the color systems discussed in this report, such an area-averaging feature is part of both the CIE and Densitometric Munsell systems and is, therefore, considered to be a definite advantage of these two color systems.

measure the optical properties of the area of the image of interest. In general, such measurements are both time consuming and difficult to make with a high degree of accuracy. Assuming accurate and precise spectral transmittance data can be collected in a few minutes, the image interpreter would still be required to perform a series of calculations before the chromaticity coordinates for the color of the object can be determined. Because of the tedious nature of these calculations, some type of automated data-handling capability would be required. Thus, it would be costly in terms of both time and money if every image interpreter were equipped with his own "black box" that read out the chromaticity coordinates (x, y) and lightness value (Y) for colors of objects which he was observing through a viewfinder.

Another disadvantage of the CIE color system is that it is difficult to relate chromaticity coordinates, lightness value, excitation purity, and dominant wavelength to the visual perception of color. For example, $x = 0.490$, $y = 0.301$, $Y = 36\%$, $p_e = 46\%$, and $\lambda_d = 640$ nm are not quickly recognized by most people as being a possible color for a red barn. Thus, there is a considerable gap between the CIE designation for a color and common understanding. This communication gap could cause a considerable problem in trying to establish some type of ground truth information by reports based on strictly visual observation of the target of interest.

(Judd and Wyszecki, 1963; Wyszecki and Stiles, 1967; Billmeyer and Saltzman, 1967; Judd, 1970)

5.1.3 ISCC-NBS Color System

5.1.3.1 The Concept and Description of the ISCC-NBS Color System

The ISCC-NBS* Color System was initially designed to aid in determining and specifying the colors of drugs and chemicals. In recent years, it has found a much wider application in many areas of industry and science. Ths ISCC-NBS system is essentially the result of applying a color-naming scheme to the Munsell system. As previously discussed, Hue, Value, and Chroma are the three dimensions of the Munsell color space, and they are arranged so that they form a cylindrically shaped color solid. All colors that have a similar Hue, Value, and Chroma will be contained in a small cell or volume within this solid. The concept of the ISCC-NBS

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* ISCC-NBS - Inter-Society Color Council - National Bureau of Standards

system is that all colors whose Munsell coordinates fall within this cell will be called the same name. To conform with the existing color-naming conventions, the Munsell color volume was arbitrarily divided into 267 individual color cells or color volumes. The Hue circle of the Munsell system was divided into 28 parts and given the names listed in Figure 5.3. The modifiers to be used with these Hue names were selected to denote the relative Chroma and Value of the colors contained within a given cell. Examples of these Hue Modifiers are shown in Figure 5.4 for a purple Hue.

5.1.3.2 The Application of the ISCC-NBS Color System to Color Imagery

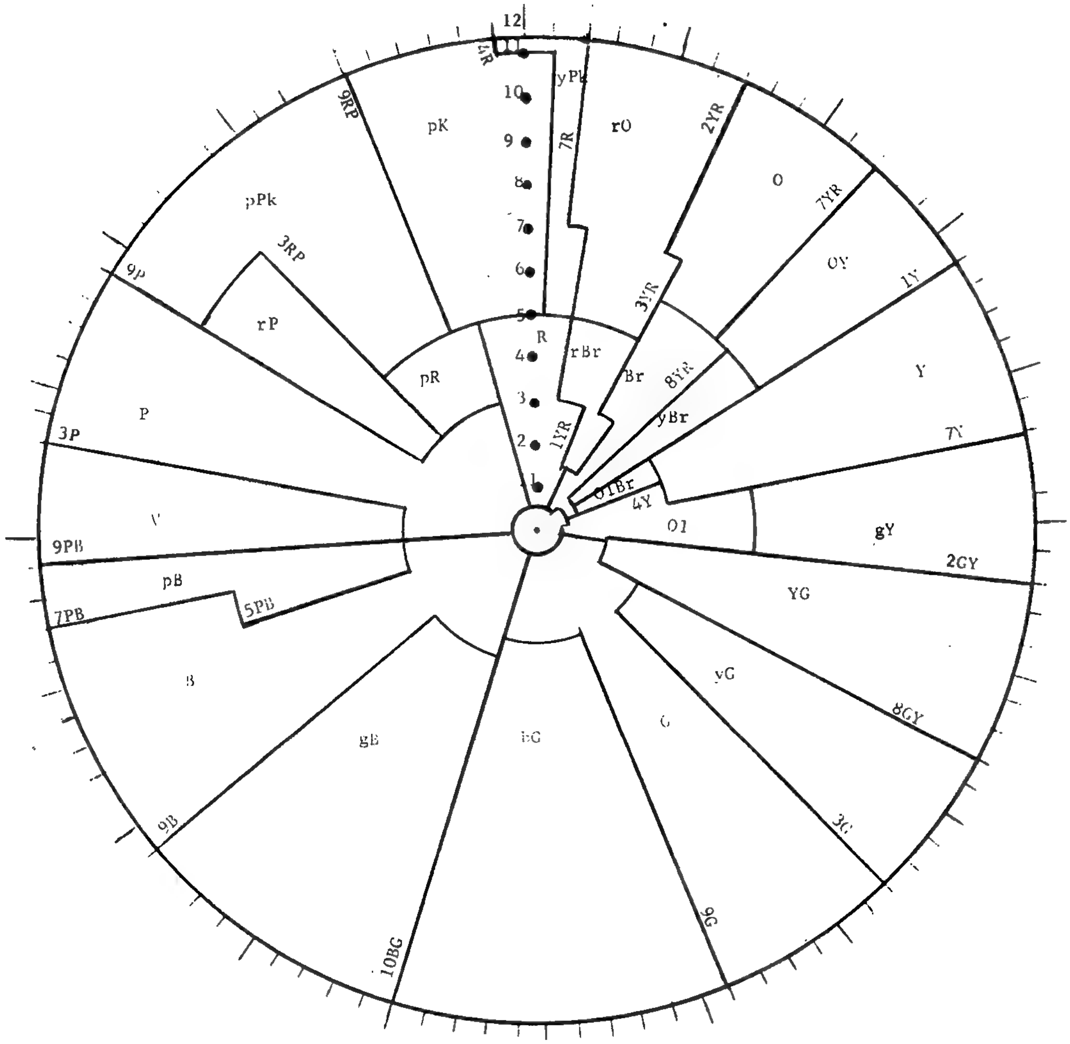
The ISCC-NBS name for the color of an object in a backlighted color transparency would be determined by the image interpreter visually selecting the frontlighted ISCC-NBS chip whose color was the nearest visual match to the color of the object. For example, the ISCC-NBS chip that visually might be the nearest match for the color of a military vehicle might be dark grayish-olive. If the ISCC-NBS system were used, some type of special eyepieces or viewing instruments would be needed so that the image interpreter or photoscientist could view the backlighted imagery and the frontlighted ISCC-NBS chips simultaneously.

5.1.3.3 The Advantages of the ISCC-NBS Color System

The principal advantage of the ISCC-NBS Color System is that it is a standardized color designation system which uses words rather than numbers or letters to designate color. Further, these color descriptors adequately communicate the visual appearance of a color in terms of a standardized color vocabulary. For this purpose, the ISCC-NBS system is the best color vocabulary that has been developed to date. Also, the ISCC-NBS color names are related to a set of standardized samples that have unique Munsell and CIE designations and the system appears to be easy to understand and to apply.

5.1.3.4 The Disadvantages of the ISCC-NBS Color System

There are several disadvantages to the ISCC-NBS Color System. As would be expected for any color system that uses painted chips, the ISCC-NBS system has a limited gamut of colors. Nevertheless, as with the Munsell color system, the ISCC-NBS color gamut is large enough to enclose



Name	Abbreviation	Name	Abbreviation
Red	R	Purple	P
Reddish orange	rO	Reddish purple	rP
Orange	O	Purplish red	pR
Orange-yellow	OY	Purplish pink	pPk
Yellow	Y	Pink	Pk
Greenish yellow	gY	Yellowish pink	yPk
Yellow-green	YG	Brownish pink	brPk
Yellowish green	yG	Brownish orange	brO
Green	G	Reddish brown	rBr
Bluish green	bG	Brown	Br
Greenish blue	gB	Yellowish brown	yBr
Blue	B	Olive-brown	OlBr
Purplish blue	pB	Olive	Ol
Violet	V	Olive-green	OlG

FIGURE 5.3 THE ISCC-NBS HUE NAMES AND ABBREVIATIONS FOR A CONSTANT MUNSELL VALUE OF SIX (Judd and Wyszecki, 1963; Judd and Kelly, 1955)

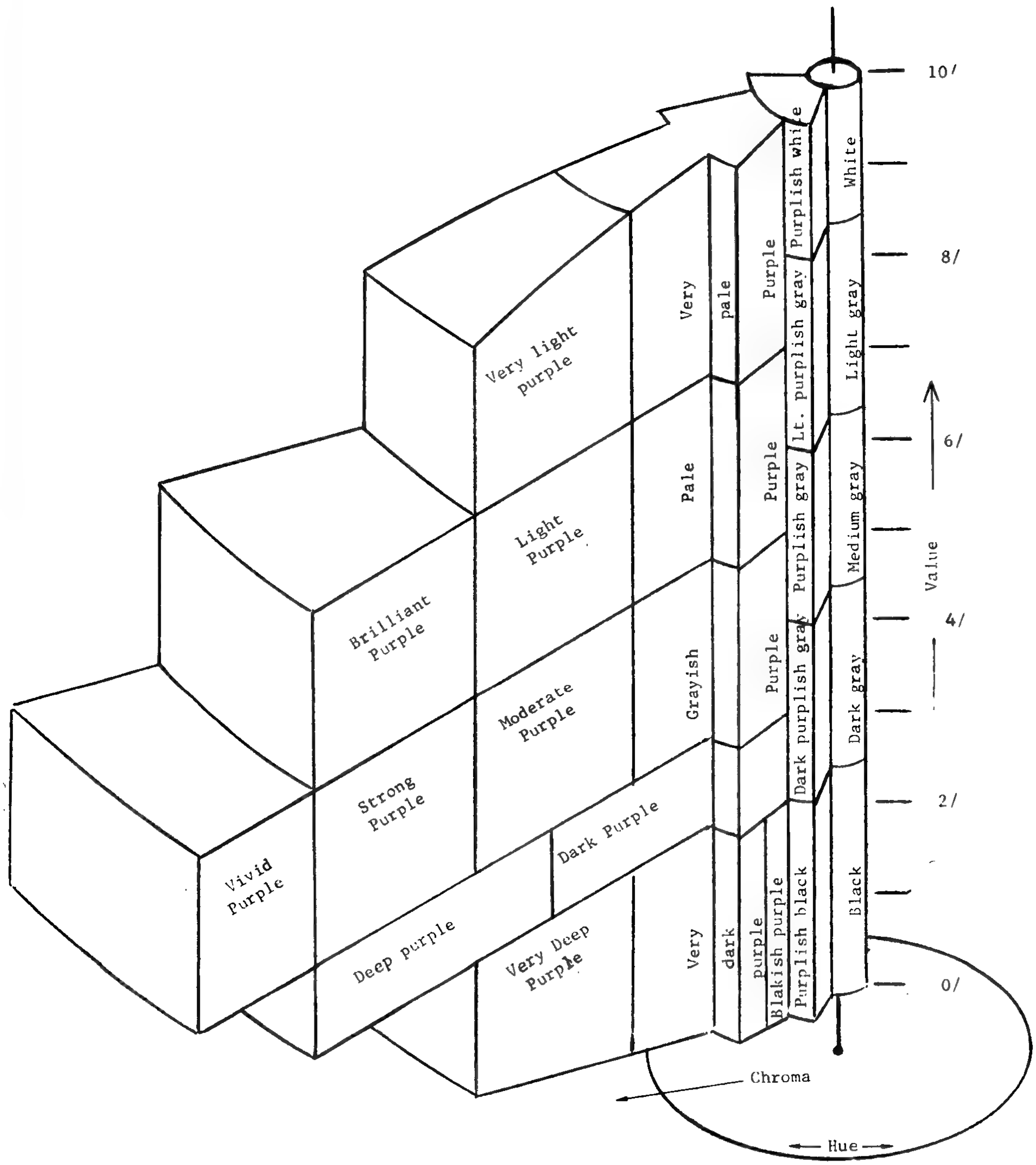


FIGURE 5.4 THE ISCC-NBS MODIFIERS FOR A PURPLE HUE
(Judd and Wyszecki, 1963)

most of the colors that might be acquired on the imagery used by the Center. Another disadvantage of the ISCC-NBS color system is that it is a discrete rather than a continuous color system.

(Judd and Wyszecki, 1963; Judd and Kelly, 1955)

5.1.4 Lovibond Color System

5.1.4.1 The Concept and Description of the Lovibond Color System

The Lovibond color system is a color-specification system based on a set of glass filters called Lovibond glasses. The various glasses are made with a thin layer of colored glass flashed onto a clear glass substrate. The red (R), blue (B), and yellow (Y) glasses* used in the Lovibond filters are made by adding gold, cobalt, and chromium, respectively, to the glass during the manufacturing process. Although these glasses are calibrated in arbitrary units, there is a definite relationship between glasses of the same or different colors. For example, a 6Y designation indicates that this particular Lovibond glass has the same spectral transmittance as six 1Y Lovibond glasses in series, and it might be used to designate a yellow-appearing Lovibond glass that had a certain thickness of a chromium-enriched glass flashed on the clear support. Similarly, a Lovibond glass designated as a 1R + 7B would have the same spectral transmittance as a series of glasses composed of one 1R Lovibond glass and seven 1B Lovibond glasses. The spectral transmittance of each Lovibond glass is adjusted so a combination of glasses with equal red, blue, and yellow designations would approximate a neutral density filter. For example, a combination of Lovibond glasses designated as 10R + 10B + 10Y would approximate a 1.3 neutral density filter.

5.1.4.2 The Application of the Lovibond Color System to Color Imagery

The Lovibond designation for a color of interest would be determined by having the image interpreter or photoscientist use some

* The spectral transmittance curves for the red, blue, and yellow glasses indicate they are really magenta, cyan, and yellow glasses. Nevertheless, the conventional red, blue, and yellow notations are used.

modified form of a Lovibond colorimeter. One-half of the interpreter's field of view in such a device would be filled with that image whose color was to be determined and the other half of his field of view would be filled with Lovibond glasses. He would change the Lovibond glasses in the colorimeter until he found the combination whose color was the closest visual match to the color of the target. For example, 20B + 30Y might be the Lovibond color designation that an image interpreter would report as being the match for a given grassy area surrounding a military complex.

5.1.4.3 The Advantages of the Lovibond Color System

The main advantage of the Lovibond system is that the glasses are stable, standardized, and transparent. Because the color samples are transparent, the same light source can be used to backlight both the imagery and the Lovibond glasses. Although having both the imagery and the standard color samples backlighted does not eliminate all the problems in visual color matching, it should reduce some of the expected problems. The Lovibond designations for the color can be transformed to the CIE chromaticity coordinates and the lightness value. The gamut of color created by various combinations of Lovibond glasses is approximately the same size as the color gamut produced by various combinations of the cyan, magenta, and yellow dyes that are used in SO-242. Another advantage of the Lovibond system seems to be its simplicity and ease of application to many practical color-matching problems.

5.1.4.4 The Disadvantages of the Lovibond Color System

One disadvantage of the Lovibond color system is that it is difficult to relate the Lovibond designation to the visual perception of color and such common color terms as light blue, dark red, and bright green. This problem might cause considerable trouble if an attempt were made to communicate color-related information by using this system. Another disadvantage of the Lovibond color system is that it requires a large number of glass filters and, therefore, would be rather cumbersome to use. Because of these disadvantages, the Lovibond system is not recommended as part of the color vocabulary.

(Judd, Chamberlin, and Haupt, 1962; Wyszecki and Stiles, 1967)

5.1.5 Densitometric Munsell Color System

5.1.5.1 The Concept and Description of the Densitometric Munsell Color System

The densitometric Munsell color-measurement system is based on the Munsell color-order system and it is designed to be used for extracting colorimetric information from prints and transparencies. However, in this case, the Munsell Hue, Value, and Chroma of the color of an image is determined by making measurements with densitometers and doing calculations by using nomographs rather than visually matching the color of a target with the color of a Munsell chip. The nomographs that are used to assist in the calculations were constructed by measuring the red, blue, green, and visual reflection densities of a set of selected Munsell chips. Although the Munsell chips are opaque, the Munsell designation for the color of a target on a transparency can be determined by using the same nomograph provided that the transmission densitometer has the same optical characteristic (e.g., acceptance angle, transmittance of filters, etc.) as the reflection densitometer used in the construction of the nomographs.

To determine the Munsell color designation of a target in an aerial photograph, the red, blue, green, and visual reflection or transmission densities of that target are measured. The difference between the highest and lowest density reading and the difference between the intermediate density reading and the lowest density reading are calculated by the image interpreter. The ratio of these differences is also calculated. The image interpreter determines the Munsell Hue, Value, and Chroma of the image by using these calculated values and the nomographs that were described above.

5.1.5.2 The Application of the Densitometric Munsell to Color Imagery

If the densitometric Munsell method of color designation were used, the red, blue, green, and visual densities of the image would be determined with a calibrated transmission densitometer. The necessary calculations to determine the required density differences and the ratio of these density differences could be done manually or automatically if the data were fed into a small computer. If the calculations were done manually, the interpreter would determine the Munsell Hue, Value, and Chroma for the color of the target by using the appropriate nomographs. If the calculations were done by a computer, the computer might be programmed to determine the Munsell Hue, Value, and Chroma of the color of

the target. The difference between these two methods is the amount of time spent between initial acquisition of the data and the determination of the Munsell designation for the color of the target.

5.1.5.3 The Advantages of the Densitometric Munsell Color System

The principal advantage of the Densitometric Munsell method is that it is a relatively simple and fast nonvisual procedure for determining the Munsell Hue, Value, and Chroma for the color of an image. Furthermore, these Munsell designations for a color can be transformed easily to their corresponding CIE color designations. Another advantage of the Densitometric Munsell system is that it can be used with either prints or transparencies. In addition, if the target area is large enough to completely fill the aperture of the densitometer, then the Munsell designation as determined by the Densitometric Munsell method is an area weighted or averaged Munsell color designation.

5.1.5.4 The Disadvantages of the Densitometric Munsell Color System

The main disadvantage of the Densitometric Munsell Color System is that there has not been sufficient verification of its applicability to color transparencies. The nomographs which have been published to date were constructed and verified by using opaque Munsell chips and color prints. Thus, there must be a considerable amount of experimental work completed before the Densitometric Munsell System could be used with color transparencies.

Another disadvantage of the Densitometric Munsell Color System is that the aperture openings on the conventional densitometer such as the Macbeth TD-102 or RD-100 are at least 1 mm or larger in diameter. Small aperture sizes are not used in these densitometers because the densitometers were designed to measure diffuse optical density rather than specular optical density of photographic materials. Most of the targets that are expected to be of interest will have image sizes which are considerably less than 1 mm in diameter. The use of such small apertures might cause some very difficult calibration problems. Because of these disadvantages, the Densitometric Munsell is not recommended for the color vocabulary.

(Gurley, Rib, and Miles 1968)

5.1.6 DIN Color System

5.1.6.1 The Concept and Description of the DIN Color System

The DIN (Deutsches Industrie Normen) color system is the official German color system. The three DIN color coordinates are called Farbton (T), Sättigung (S), and Dunkelstufe (D). In the DIN system, D is defined* as a logarithmic function of the relative lightness which is the ratio of the luminous reflectance of the color sample to the maximum luminous reflectance of all those colors that have the same chromaticity coordinates as the sample. The D scale is equally spaced for both chromatic and achromatic colors. The dominant wavelengths of the twenty-four different Farbton used in the DIN system were selected so that the different colors would be spaced in nearly equal steps. The lines radiating from the point representing the CIE standard source C in Figure 5.5 are lines of constant DIN-Farbton or constant T. The curves enclosing the point representing the C source on the CIE diagram in Figure 5.5 represent levels of equal visual saturation or constant, S.

5.1.6.2 The Application of the DIN Color System to Color Imagery

It is anticipated that the opaque DIN color samples could be used in some type of visual colorimeter. The DIN color samples would appear, one at a time, on one side of a bipartite field of view while the image of interest would appear on the other side of the field of view. The observer would designate the color of the target as being the same as the color of the DIN color sample that was the closest visual match to the color of the image. Of course, the color designation of the target would be expressed as so many units of T:S:D. For example, a yellow rose might be designated as 2:6:1 in the DIN color system.

5.1.6.3 The Advantages of the DIN Color System

An advantage of the DIN system is that it is a psychological system which is based on the visual perception rather than the physical aspects of light. Furthermore, the DIN designation for the color of an object can be transformed to other color systems such as the Munsell and CIE.

* Literally translated it means "darkness degree".

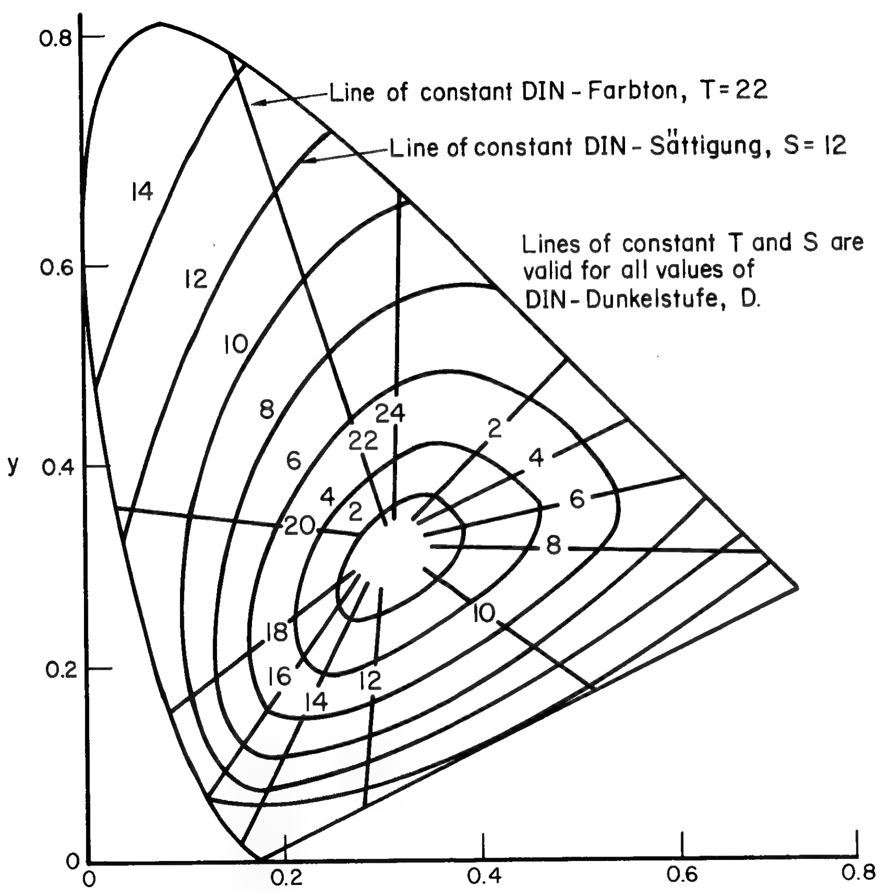


FIGURE 5.5 THE LINES OF CONSTANT DIN-FARBTON AND DIN-SÄTTIGUNG PLOTTED ON A 1931 CIE DIAGRAM

5.1.6.4 The Disadvantages of the DIN Color System

The very limited use of the DIN Color System outside Germany is a definite disadvantage. It would be difficult to write equipment specifications in terms of DIN color standards for contracts with American manufacturers. Another disadvantage of the DIN system is that it is difficult to relate the numerical DIN designations for T, S, and D to the colors they represent. Further, the DIN system is a discrete rather than a continuous color designation system. Because of these disadvantages, the DIN system is not recommended for the color vocabulary.

5.1.7 Ostwald Color System

5.1.7.1 The Concept and Description of the Ostwald Color System

The Ostwald Color System, which is very useful to artists and decorators, is based on Ostwald's philosophical concept that colors could be characterized by what he defined as their full color content, black content and white content. How these concepts were applied by Ostwald is illustrated in Figure 5.6. The spectral reflectance curve is for an idealized colorant because such step-like changes in spectral reflectance can only be approximated by an actual dye or pigment. The white content, black content, and full-color content of such idealized colors were defined so that their sum would equal unity (i.e., B+W+C = 1). For a color defined in this manner, the standard Ostwald notation consists of a combination of numbers and a word that specifies one of the twenty-four hues used by Ostwald and two lower-case letters whose combination denotes the white and black content of the color. The first letter in this notation specifies the white content of the color and the second letter specifies the black content of the color. Although the lower-case letters in Figure 5.6 are the standard Ostwald notation, the numerical values for the white, black, and full-color content of the various colors have been included. For example, the Ostwald notation "ne" denotes an Ostwald hue that has a white content of 5.6 percent and a black content of 44.0 percent.

The idealized colors in the Ostwald system have some very interesting colorimetric properties. For example, the colors in any one of the diagonal columns have the same dominant wavelength but the colorimetric purity increases as one moves toward the outer boundary of the diagram. Those colors in any vertical column have the same chromaticity coordinates or constant excitation purities, but their lightnesses

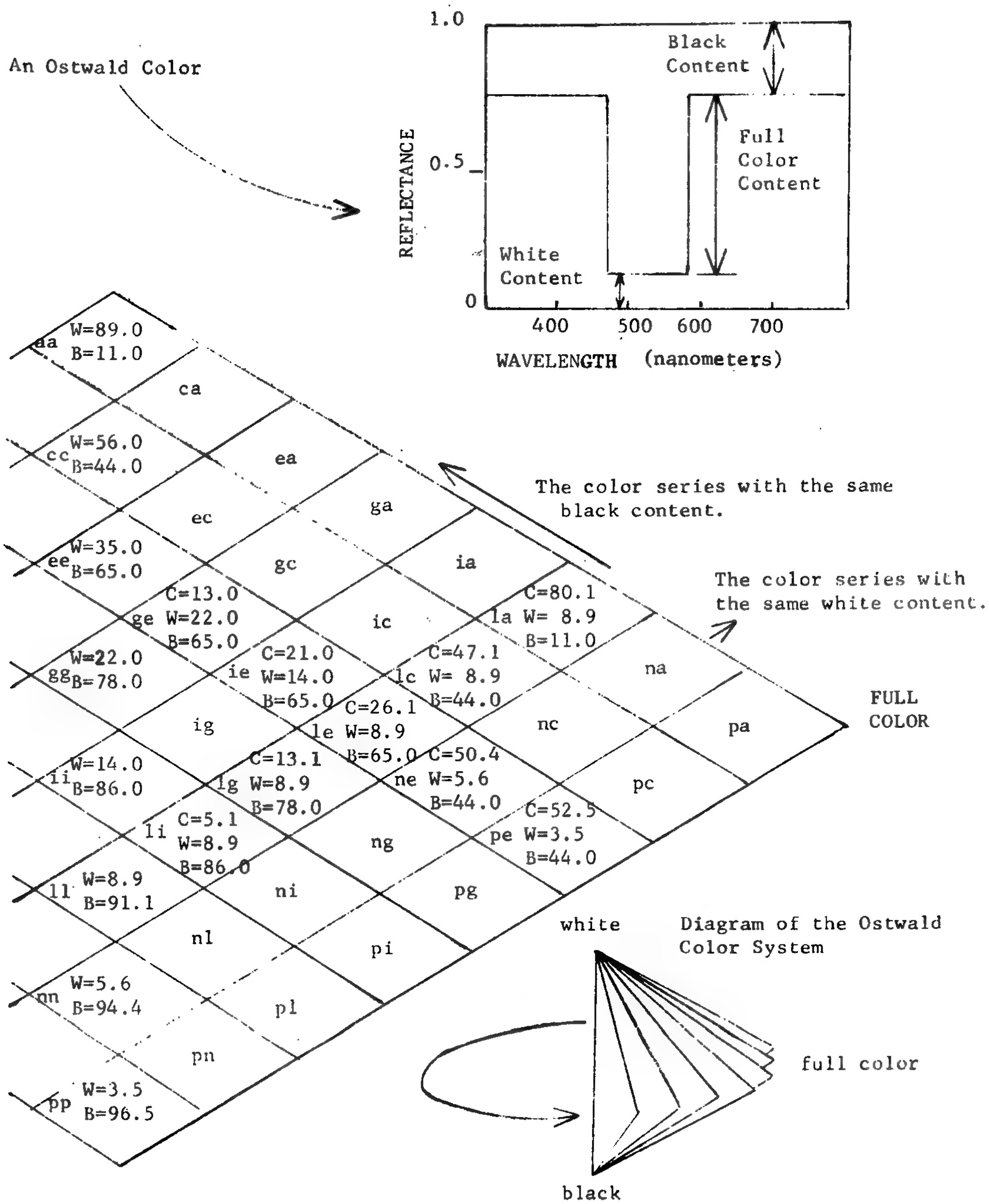


FIGURE 5.6 THE OSTWALD COLOR SYSTEM

increase as one moves from the bottom to the top. The hues are arranged in a circular pattern as shown in the small diagram at the lower right of Figure 5.6 and represent approximately equal intervals of visual perception.

5.1.7.2 The Application of the Ostwald Color System to Color Imagery

The Ostwald designation for the color of an object in a backlighted color transparency would be determined by visually selecting the frontlighted opaque Ostwald color chip that was the nearest visual match to the color of the object. If this system were to be used, some type of special viewing equipment would be necessary so that the image interpreters could view simultaneously the backlighted color transparency and the frontlighted opaque Ostwald chip.

5.1.7.3 The Advantages of the Ostwald Color System

An advantage of the Ostwald Color System is that the colors in any diagonal series such as aa, ca, ..., pa or ii, ig, ..., ia, increase in excitation purity (p_e) while maintaining a constant dominant wavelength. Similarly, those colors in a vertical series such as pn, nl, ..., ca represent a series of colors which have a constant value for excitation purity but increasing values of lightness. These are advantages because they represent the way most individuals visualize colors.

5.1.7.4 The Disadvantages of the Ostwald Color System

The principal disadvantage of the Ostwald Color System is that real colorants do not behave in the manner predicted by Ostwald. Further, the chips must be frontlighted which is a definite disadvantage. Also, it is difficult to visualize the color represented by the Ostwald notations for the various colors. Because of the absence of any unique advantages, the Ostwald Color System is not recommended for the color vocabulary.

(Evans, 1948; Evans, Hanson, and Brewer, 1953)

5.1.8 NuHue, Plochere, Ridgway, Maerz & Paul, Villalobos, Textile Color Card Association, and Methuin

5.1.8.1 The Concept and Description of the NuHue, Plochere, Ridgway, Maerz & Paul, Villalobos, Textile Color Card Association, and Methuin Color System

All of the color-naming systems listed in this title consist of an orderly arrangement of colored plaques or chips. These color systems were designed for use by a specific industry or profession. For example, the Ridgway system is used by biologists for labeling specimens and the NuHue system is used by the paint industry to specify the color of paints. These systems are quite adequate for the specialized purposes for which they were designed; however, it is difficult to tell anything about a color from the name given to it by these various color systems. The ISCC-NBS color "light blue" is "Diana", "Good Omen", "King's Blue", and "Forget-Me-Not" by Maerz and Paul, Plochere, Ridgway, and the Textile Card Association, respectively. In some of these systems, the color chips or samples were made by using paints whose composition was unknown or cannot be duplicated.

5.1.8.2 The Application of the NuHue, Plochere, Ridgway, Maerz & Paul, Villalobos, Textile Color Card Association, and Methuin Color System to Color Imagery

The NuHue or similar designations for the color of an image in a backlighted color transparency would be determined by visually selecting the frontlighted opaque color chip whose color most closely matched the color of the image. If the NuHue or similar system were used, some type of special viewing equipment would have to be used so that the image interpreter could simultaneously view the backlighted images and the frontlighted color chips.

5.1.8.3 The Advantages of the NuHue, Plochere, Ridgway, Maerz & Paul, Villalobos, Textile Color Card Association, and Methuin Color System to Color Imagery

The principal advantage of these color systems is that they designate colors by names which are somewhat descriptive of the color. This would be a very definite advantage in trying to communicate color-related information in a written or oral form.

5.1.8.4 The Disadvantages of the NuHue, Plochere, Ridgway, Maerz & Paul, Villalobos, Textile Color Card Association, and Methuin Color Systems

The principal disadvantage of these color systems is that, in many cases, they lack any plan or design in the selection of the colors they have used. When these color systems were developed, there was no attempt made to select colors or to arrange them in any manner that correlated to either the physical or psychological aspects of color. Furthermore, most of the systems lack adequate standards so that it is very difficult to reproduce the color samples accurately. Another disadvantage in using such a pigmented sample is that they provide only a very limited gamut of colors. Because of these disadvantages, these color systems are not recommended for the color vocabulary.

(Evans, 1948; Wyszecki and Stiles, 1967; Judd and Wyszecki, 1963)

6.0 CONCLUSIONS AND THE RECOMMENDED COLOR VOCABULARY

6.1 THE CONCLUSIONS OF THE REVIEW OF THE PROBLEMS RELATED TO THE DEVELOPMENT OF A COLOR VOCABULARY FOR THE CENTER

The four major problem areas related to the development of a color vocabulary have been discussed in Sections 2.0, 3.0, 4.0, and 5.0. These four major areas are (1) the visual problems related to the interpretation of color imagery, (2) the photographic problems related to the interpretation of color imagery, (3) the job-related color needs of the individuals, and (4) the applicability of various color systems to the problem of identifying, reporting, and catalogueing the colors of images. In each instance, conclusions refer specifically to the color-related problems at the Center.

The visual problems that are related to the interpretation of small-scale, high-quality color imagery were discussed in Section 2.0 of this report. From the experimental results presented in these discussions, it is evident that under well-controlled viewing conditions, the average color-normal individual has a tremendous capacity to accurately and reliably discriminate differences, i.e., by comparative judgment between the colors of two structure-free fields. The accuracy and precision of these color-discrimination judgments that are made by the average color-normal observer will deteriorate rapidly if the viewing conditions are not well controlled and maintained. Nevertheless, even with poorly controlled viewing conditions, the accuracy and reliability of his comparative judgments will probably be greater than his color memory or any other absolute color judgment. However, his color memory can be improved by practice and frequent practice of the exercises. On the basis of this evidence, it is concluded that a color vocabulary which consists of more than fifteen to twenty different colors must be used with some type of a visual color-reference system. Furthermore, the viewing conditions for using this visual color-reference system must, in part, be clearly specified, understood, and used. In addition, the color vocabulary must be able to designate a large number of colors because of the color-discrimination ability of the typical observer.

Some of the photographic problems of small-scale color imagery which were considered to be relevant to the color vocabulary were discussed in Section 3.0. Images of targets expected to be of interest to the Center would generally have an angular size of less than two degrees when viewed at the maximum useable magnification (60x). Fields of view whose angular sizes are the order of one-to-two degrees or larger are considered necessary for accurate and reliable color matching or color discrimination. Therefore, it is concluded that because of the small angular size of the

targets of interest, it will be difficult but not impossible to use a visual matching technique to reliably determine the colors of an image.

The color fidelity of imagery acquired by using acquisition films such as SO-242 or SO-255 was also discussed in Section 3.0. It was stated that the color fidelity or color-rendering properties of color reversal films such as SO-255 or SO-242 were degraded because the photochemist also had to consider factors such as resolution, dye stability, and cost in his selection of the sensitizers and the colorants. It was demonstrated in Section 3.1 that noticeable color shifts or color variations can result from small changes or variations in exposure. Similarly, color shifts of the same magnitude can be expected for variations in other acquisition factors, such as sun angle and atmospheric conditions over the target. It is apparent from these results that, at best, the image colors will be only close approximations to the actual or "ground-truth" colors of these objects. It is also apparent that the image colors of an object will vary on a mission-to-mission basis if not on a frame-to-frame basis. Thus, any accurate measurement of the image color will be only the best approximation to the actual color. It is concluded that any color vocabulary that might be used by the Center must be capable of accounting in some way for these variations in the image color of a target if the actual color is to be determined. Furthermore, the ground-truth color of a target can not be determined solely from the information that can be extracted from the imagery because color photography is an integrating process. To determine the actual color of an object, the image interpreter or photo-scientist must use some type of an acquisition model which includes and accounts for such variables as sun angle and atmospheric effects. If such a model or correction formula were not available, precise measurements would not be of value and a less accurate measurement system would suffice. Hence, one of the outputs of the color vocabulary should be color-related data that can be used as an input to an acquisition model which would be used to determine the actual color of the object.

In order to account for the color communication needs of the personnel described previously, it is concluded that a tri-dimensional or three-level color vocabulary is needed. One level of this color vocabulary would need to be a color-measurement system that was capable of designating a large number of colors and the output of which would be a notation indicating the precise value of the color. This level of the color vocabulary would be used for exact and precise color communication. Another level of this color vocabulary would be needed for the verbal and visual communication of the colors. Such a system must contain a set of reference colors. Finally, a simple set of color names could be used when accurate and precise color identification is not needed or could not be obtained. These color names would simply communicate the general color, e.g., blue, blue-green, yellow, etc..

Finally, from the study of the color system, it was concluded that the Munsell, CIE, and ISCC-NBS color systems were the best of the available color systems for the color vocabulary. The CIE color system was selected because it is (1) precise, (2) continuous, and (3) related to the physical aspects of color. The Munsell color system was selected because it is a visual color reference system that contains a large number of color samples and is related to the visual and psychological aspects of color. The ISCC-NBS color system was selected because it uses a set of standardized color names that are quite descriptive (e.g., vivid red) of the colors they represent, and the color samples are related to the Munsell system.

6.2 THE CONCEPT OF A MULTILEVEL COLOR VOCABULARY

A color vocabulary based on a single color system did not appear to adequately satisfy the needs of the individuals at the Center and its overall color-related mission requirements. However, many of the requirements that have been placed on the color vocabulary could be satisfied by a multilevel color vocabulary whose structure would be similar to, if not the same as, the "universal color language" described by Kelly (1965). The lowest level suggested by Kelly would consist of approximately fifteen colors and neutrals that would be designated by their generic hue names such as red, blue, green, ..., white, gray, and black. The complexity of the color system and the number of colors would increase as the level of the color system increased. Kelly has proposed that the ISCC-NBS system be used for the middle level of the universal color language. The ISCC-NBS color system has 267 colors which are described by both hue names and modifiers such as "vivid red" and "very dark yellow-green". The upper level of the universal language described by Kelly has the greatest accuracy of identification and uses a system such as the CIE or Munsell. Thus, in passing from the lowest to the highest level, both the accuracy of color identification and the complexity of the system has been increased greatly. The principal advantage of such a multilevel vocabulary is that each level not only satisfies a particular set of color communication needs, but also relates to those at all other levels. Also, the "color resolution" or accuracy of color identification can be increased easily by simply moving to the next higher level.

It is concluded that the level of the color vocabulary used by the individuals at the Center is dependent upon the type of color-related information the individual is trying to communicate rather than his specific job requirement. For example, in some cases, merely creating the impression of a color is sufficient; therefore, a set of simple color names is all that is required. In those cases where a more precise impression of the color must be communicated, the individuals would both visually and verbally

communicate the color. Here the ISCC-NBS or Munsell color system which contains color-reference samples would be used. Which of these is used is dependent upon the accuracy required. Lastly, for those who want to communicate the physical aspects of color, the CIE system would be needed.

On the basis of all the preceding information, it is concluded that the color-related needs of the Center and the job-related color needs of the individuals can best be satisfied by a three-level color vocabulary. The first level would consist of approximately twenty color names such as red, blue, brown, ..., gray, and black and the lightness descriptors light and dark. A reference set of color samples would be included, but not for the purposes of matching. At this level, it is only important that the generic hue name and general lightness value of the color be indicated.

The second level of the color vocabulary should consist of some type of color reference samples that could be used in the visual communication of color related information. Either the ISCC-NBS or the Munsell color system could be used for this level of the color vocabulary. Which of these two color systems is used is dependent upon the level of precision that is needed for visual communication. The Munsell system would be used for the precise visual communication of color-related information, such as would be needed in the accurate reproduction of color imagery. The ISCC-NBS color-naming system would be used in those cases where such precision was not needed.

The third level of a color vocabulary the Center could use is the CIE system. The colors of the images would be designated in terms of their CIE chromaticity coordinates (x, y), lightness value (Y), excitation purity (p_e), and dominant wavelength (λ_d). This level of the vocabulary would also need to account for the inaccuracies of the acquisition and processing systems. Because of the complexity of the CIE system, it is anticipated that the Center would need to develop a capability for solving color-related problems which would be similar to their present capability for solving mensuration problems.

For general communication, everyone would use the first-level vocabulary. The image interpreters might report out the image color of targets (when precise requirements are not needed) by using such terms as light brown, blue, dark green. The illustrators might be requested to make a VUGRAPH that had red letters on a light yellow background. The use of the second level of the color vocabulary (ISCC-NBS or Munsell color system) would be used in those cases where the communication needs to be more precise. For example, the ISCC-NBS system might be used to report that in a given area all the tanks had been repainted a dark

olive-green instead of dark grayish olive-green. This is analogous to the situation where the image interpreter scales the length of a target and calculates its longest dimension to be somewhere between 195 and 200 feet. Similarly, the second level would be used by an image interpreter if he wanted the model maker to use light yellowish-brown paint instead of a grayish yellow paint for painting the dead grass around a chemical factory or industrial complex. In these cases, the color names would be selected by grossly matching the color image to the ISCC-NBS color chips. Since this is a gross match, complex equipment and standardized viewing conditions would not be required.

If a more precise color identification were required at this second level, the Munsell color system should be used. The individual would probably have to take his imagery or prints to experts who would determine the Munsell designation of the color under controlled and standardized viewing conditions.

The third level of the color vocabulary would be used only in those situations where it was necessary to very accurately determine the color of a target. This is analogous to the case where the image interpreter realizes it is important to know whether the width of an antenna is 10 feet or 10.125 feet. At this third level, the image interpreter would take his imagery to those individuals or that group who could make accurate color measurements and request that they determine the CIE chromaticity coordinates and lightness values for that particular target. The scientist and engineer would also use this third-level vocabulary for scientific communication, designing experiments, and writing specifications.

6.3 SELECTION OF THE FIRST LEVEL COLOR VOCABULARY

The color names for the first level color vocabulary were selected in the following way:

(1) The visual spectrum was separated into its unique hue names: red, orange, yellow, yellow-green, green, blue-green, blue, violet, and purple*.

(2) Each spectral hue was conceptually varied in lightness from light to dark to determine if unique and commonly recognized color names could be used to represent the lightness differences. This step resulted in additional color names: pink, brown, and olive.

* Although purple is not a spectral hue, it is considered a unique hue.

(3) To represent various brightness levels, the two modifiers light and dark were added to the vocabulary.

(4) To represent the gray scale, the terms white, gray, and black were chosen.

(5) The color names cyan (a blue-green) and magenta (a purple) were added because of their frequent and consistent use in color-reproduction and processing. However, these two color names are not to be used for describing image colors.

These steps resulted in a vocabulary of two modifiers, light and dark, and seventeen (17) names: pink, red, orange, brown, yellow, yellow-green, olive, green, blue-green, blue, violet, purple, white, gray, black, cyan, and magenta.

6.4 THE RECOMMENDED COLOR VOCABULARY

As a result of this study, it is recommended that the Center use a trilevel color vocabulary. The first level of this vocabulary consists of seventeen names and the modifiers light and dark. The seventeen recommended names are pink, red, orange, brown, yellow, yellow-green, olive, green, blue-green, blue, violet, purple, white, gray, black, cyan, and magenta. Combinations of any two of these names such as red-brown (except cyan and magenta) can be used in those few situations where the basic names are not adequate. The names cyan and magenta are not to be used for image colors. Samples of these colors (excluding white, gray, and black) are included in the back of this report.

It should be emphasized that these seventeen color names are recommended only as the starting point for the first level of color vocabulary. If in use at the Center it is found that some of these names are not used or that there is a need for some additional color names, then it is recommended that such changes be made by the Center.

The second level of the vocabulary consists of both the Munsell and ISCC-NBS color systems. The degree of precision needed in the visual communication of color-related information determines which of these two color systems is to be used. The ISCC-NBS color system is used when a non-precise visual color reference is required for communication. This system is implemented in normal working and viewing conditions, since the widely separated color samples do not require the use of critical color

matching. When a more precise visual color reference is required, the Munsell system is used. All the Munsell color matches or designations are made visually, under specified and well controlled viewing conditions by well trained individuals. Ideally, transparent Munsell samples are used in a split-field viewer. If, however, the dyes are too unstable to make these transparencies practical and reliable, then the matte-finished Munsell chips are used. To implement the use of the matte-finished chips, a split-field viewer may be needed. The chips are placed in one-half of the field of view and the film in the other half. The lighting in each half of the viewer is adjusted so that both the film and the chip receive equivalent illumination in terms of intensity and spectral distribution. Apertures are used in both fields to reduce the influence of the colors surrounding the target, while keeping the size of both fields of view the same. Although this device is an aid to color matching, the texture differences between the film and the matte chip may still cause perceptual difficulties. However, there is evidence that with practice and experience one can adapt to these texture differences (Parry, et al., 1969 a,b).

The third level of the recommended color vocabulary is the CIE color-designation system. To implement this third level of the recommended color vocabulary it will be necessary to develop a color-correction model to account for the effects of acquisition and processing on color fidelity. If this model is not developed, then precise color measurements would not be valid or needed. In addition, it is recommended that the Center develop the capability for performing accurate reliable color measurements and calculations by forming a colorimetric group.

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